Special Technical Report 26

# INITIAL VHF PROPAGATION RESULTS USING XELEDOP TECHNIQUES AND LOW ANTENNA HEIGHTS

By: N. SHRAUGER L. TAYLOR

Prepared for:

U.S. ARMY ELECTRONICS COMMAND
FORT MONMOUTH, NEW JERSEY

CONTRACT DA-36-039 AMC-00040 E
ORDER NO. 5384-PM-63-91



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SRI Project 4240

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## ABSTRACT

An adaptation of the Xeledop technique for study of propagation problems associated with VHF manpack radios is described and the results of initial VHF propagation tests for several frequencies, polarizations, and terrains for low antenna heights are presented.

Initial results show that the choice of frequency and antenna polarization has a significant effect on propagation in a situation similar to a possible employment of manpack radio sets. Vertical polarization was found to be superior for transmission of signals over open terrain; horizontal polarization was superior for the foliage-covered terrain of the tests. The effect of frequency was also examined and it was found that the type of terrain generally has less effect on the received signals as the transmission frequency is increased from 50 to 100 MHz.

Future propagation studies and measurements using the Xeledop technique are suggested.

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ILLUSTRATIONS

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## ACKNOWLEDGMENT

The work described in this report was performed with the cooperation of the Military Research and Development Center (MRDC) at Bangkok, Thailand, a joint Thailand-United States organization. The help of the Environmental Sciences Division of MRDC in measuring and describing the Foliaged Beach test terrain is especially acknowledged.

# I INTRODUCTION AND OBJECTIVES

Work is being conducted under the SEACORE program to gain an understanding of the problems affecting the performance of field radio sets used in tropical areas. The work reported here is the first phase of a program whose objective is to increase the understanding of VHF propagation in forests, with special emphasis on manpack radio communications. Measurements are conducted with low antenna heights to simulate patrol conditions.

The specific objectives of these tests are to determine the following:

(1) Received signal strength vs. distance for very short ranges and low antenna heights

(2) Differences in propagation through various types of foliage

(3) Differences in propagation between open and forested areas

(4) Effect of polarization on received signal for various frequency and foliage combinations

(5) Frequency dependency of effects examined in Objectives 1, 2, and 3.

This report discusses the experimental method and the results obtained from investigations made in open delta and open and foliaged sandy beach terrains.

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## II GENERAL DESCRIPTION OF TEST TECHNIQUE

In studying the effect of foliage upon radio signal propagation, it is essential that variables introduced by the measuring equipment be minimized in order to achieve any significant success. Previous experience[1*] has shown that manpack radio equipments are not satisfactory for use in this kind of experiment. The manpack radio is typically designed for low-duty-factor operation and does not possess the long-term stability required for these measurements. Changes in transmitter power output and receiver drift have been found to be especially troublesome.

The tests described in this report were carried out with a technique based upon the use of a Xeledop[†] transmitter. The Xeledop was developed for use in measuring the radiation patterns of full-scale HF and VHF antennas.[2,3] The chief characteristics of the Xeledop transmitter are its stable frequency and constant power output; tests have shown that the power output varies less than 1 dB and that the frequency drift is negligible over a period of eight hours.

The overall length of the VHF version of the Xeledop is small enough to make carrying of the unit on a back-pack quite feasible. The experiment consists of having a man carry the Xeledop along a surveyed trail (which is marked at intervals corresponding to the radial distances from the receiving antenna) and recording the signal strength at the receiver position. The receiving end of the system consists of a stable receiver with a half-wave dipole antenna. The receiver has provisions for obtaining an output that can be directly related to the received signal strength. This output is continuously recorded on a paper strip-chart recorder to which a calibration of signal strength can be added. As the Xeledop transmitter is moved along the trail, a second man

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[*] References are listed at the end of the report.

[†] Acronym for "Transmitting Elementary Dipole with Optional Polarity."

carrying a small hand-held transceiver walks several wavelengths ahead of the transmitter. His job is to relay to the recorder operator the transmitter's position as it is carried past each of the radius markers. These distances are marked on the chart record of the received signal strength by the receiving site operator. Thus, the experimental results are obtained as a calibrated, paper-chart recording of received signal vs. radial distance, where the radial distance varies from 0 to at least 0.3 miles.

## III TEST EQUIPMENT AND PROCEDURE

### A. Equipment

The transmitter is a VHF Xeledop that has been adapted for manpack use by mounting it on a pack frame. The Xeledop incorporates three crystal-controlled transmitters that are coupled to the antenna through a multicoupler circuit. The unit is designed to transmit on three frequencies simultaneously or in pulsed sequence on 50, 75.1, and 100 MHz. The transmitter power output at each frequency is about 0.35 watt.* Figure 1 shows the VHF Xeledop being carried in the horizontally polarized position.

The receiving test set-up is shown in the block diagram of Fig. 2; the photograph of Fig. 3 shows the equipment as arranged in the receiving van. Figure 2 shows that the half-wave dipole is connected through a balun and step attenuators to the VHF receiver. The receiver AGC voltage is recorded on a paper-chart recorder. The recorder is operated at high sensitivity (1 millivolt per division) to provide good resolution. However, using this increased sensitivity reduces the dynamic range of the recorder to about half of the dynamic range of the received signal. This imbalance is compensated for by inserting line attenuators in front of the receiver, which are adjusted during the tests to prevent the received signal from driving the recorder pen off scale. The VHF signal generator is provided for calibrating the receiver output that is recorded on the strip chart.

The receiving antennas used in the work described here were balanced half-wave dipoles. The elements were constructed of telescoping automobile

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*A description of the VHF Xeledop is given in Ref. 3; the system is covered in greater detail in SRI Internal Memorandum, "Xeledop Antenna Pattern Measuring Equipment, 50 to 100 MHz," by C. Barnes (April 1966).

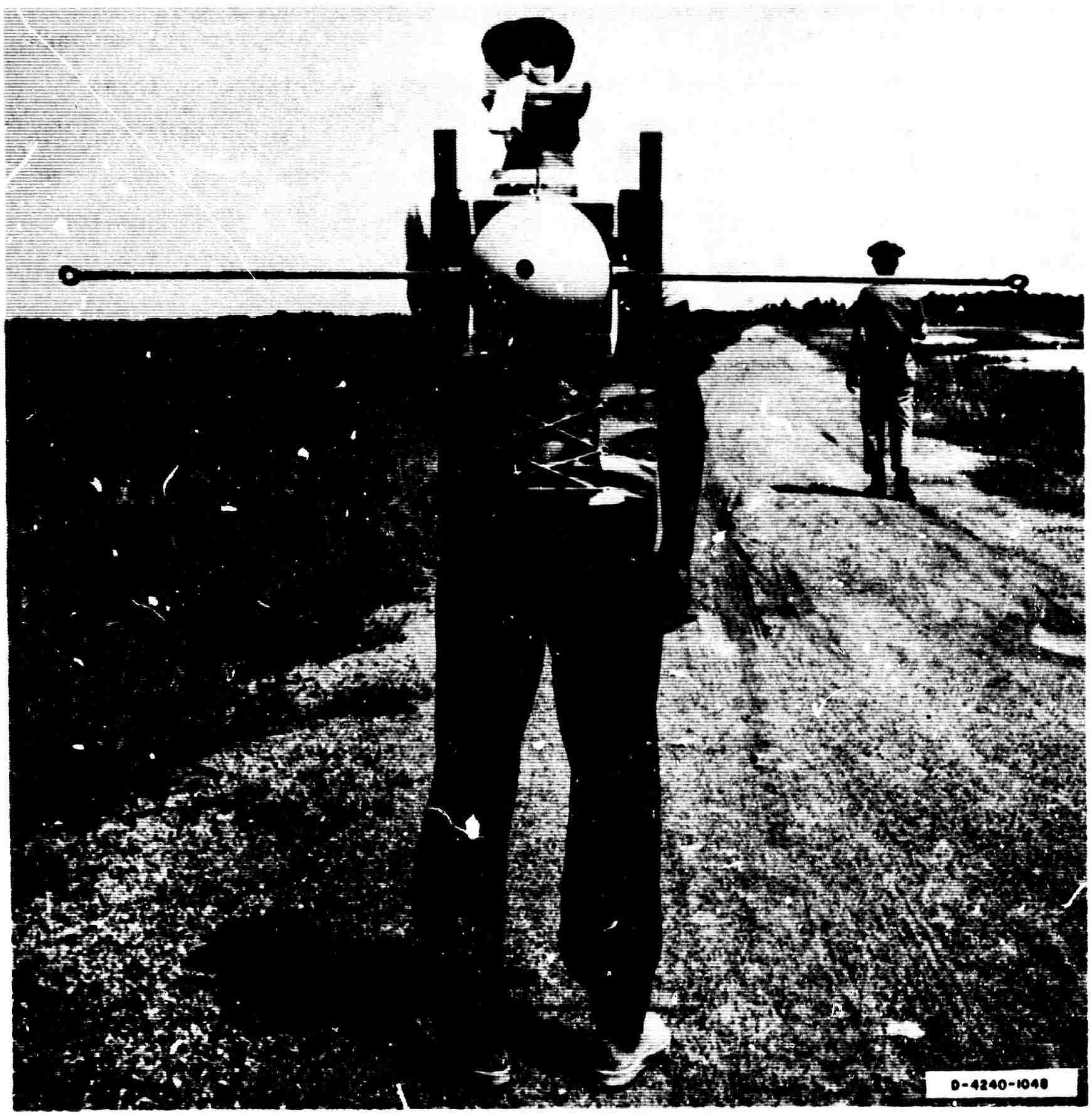


FIG. 1 THE XELEDOP USED AS A MANPACK TRANSMITTER

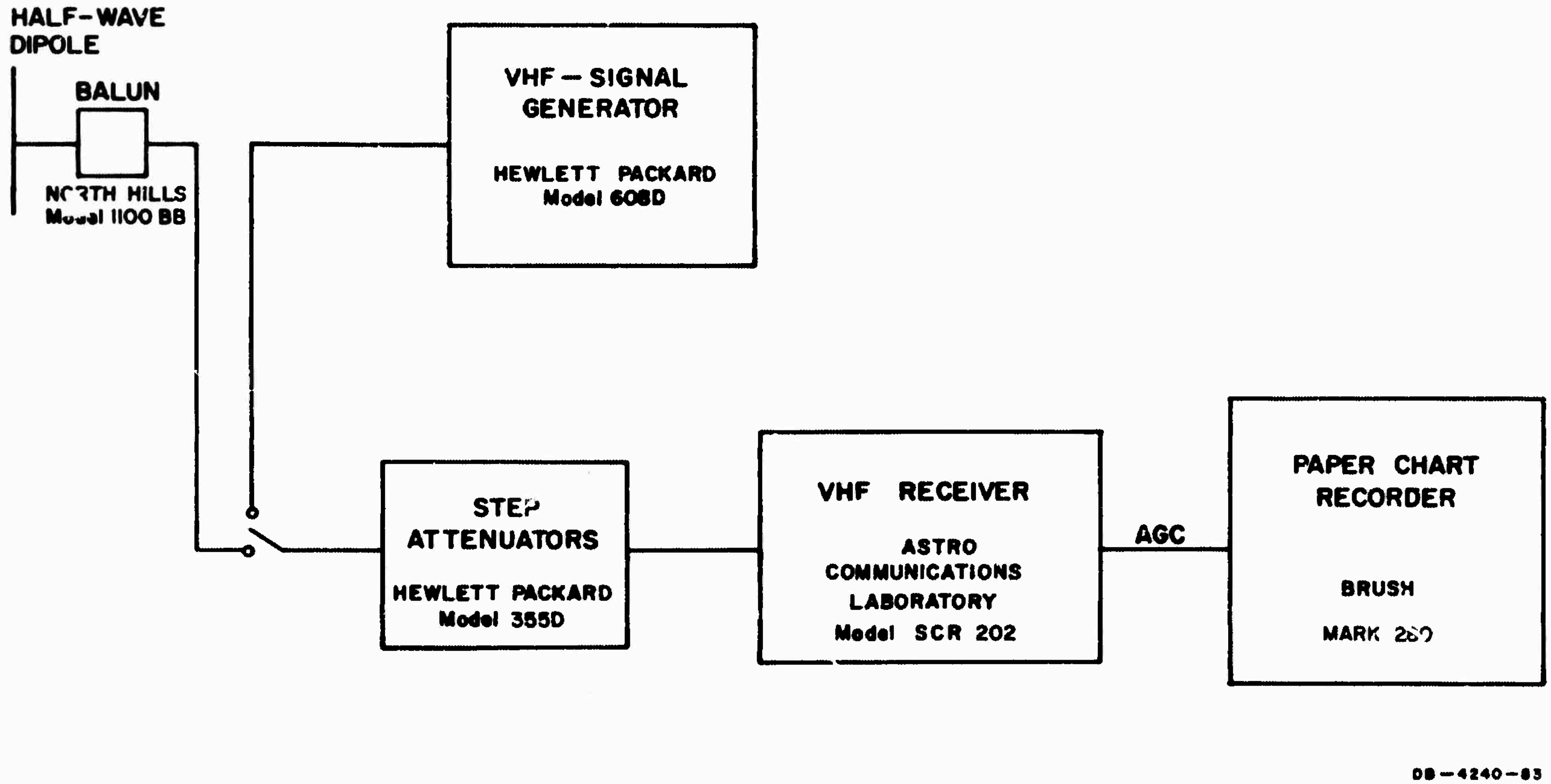


FIG. 2 RECEIVING SITE EQUIPMENT

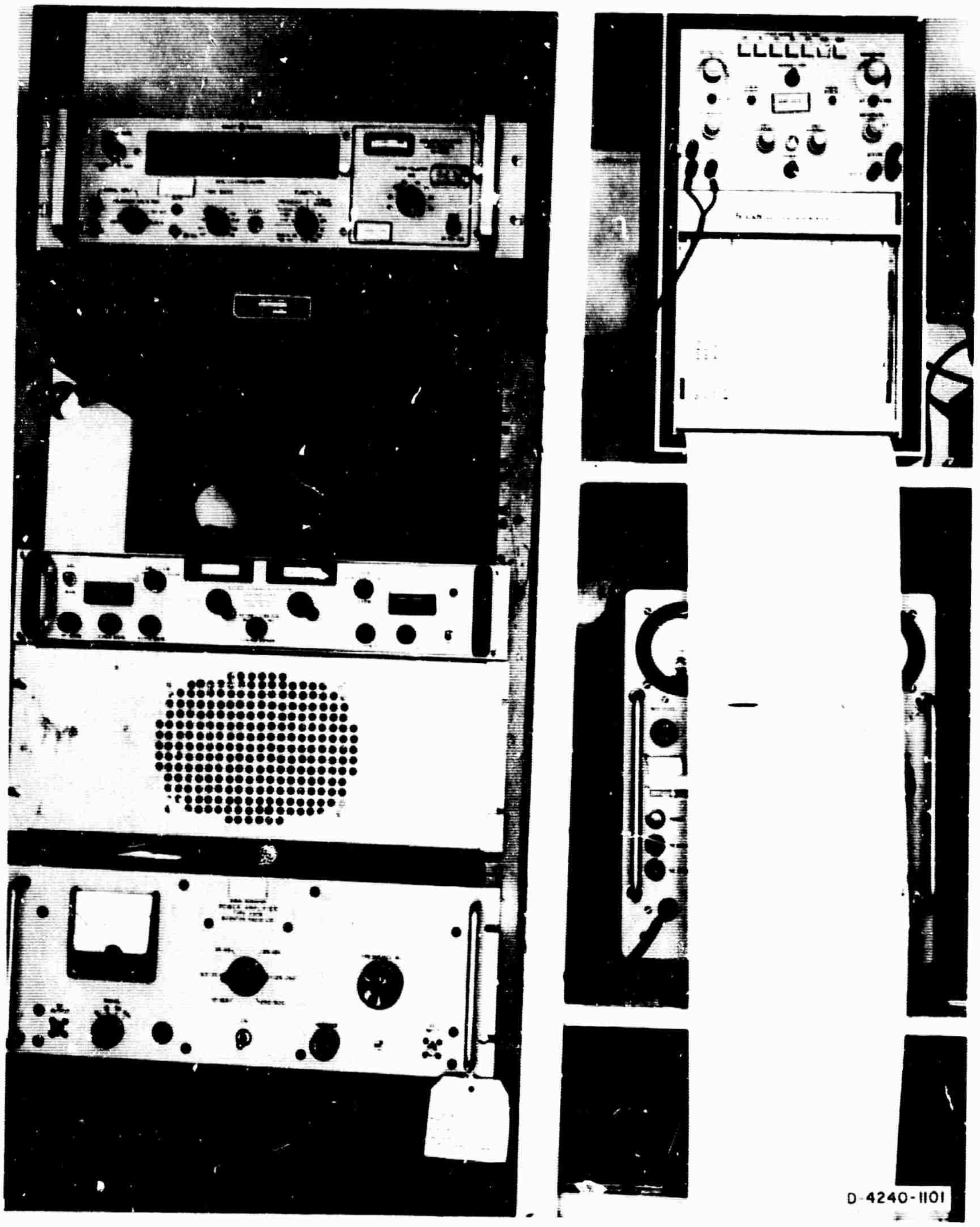


FIG. 3 RECEIVING EQUIPMENT IN TEST VAN (Left rack, top to bottom; Hewlett-Pockord 5245 counter, Astra Communications Loborotary SCR202 VHF receiver, Boanton 230A power amplifier; right rack, top to bottom: Brush Mork 2500 recorder, Hewlett-Pockard 608D VHF signal generotar.)

antennas that could be adjusted to resonant length over a wide range of frequencies. Three receiving antennas were used, one for each frequency. The resonant length of each antenna was determined for horizontal polarization at a feed-point height of 10 feet over the delta. These resonant lengths were used for succeeding tests and locations and the antenna impedance was measured at each location. Appendix A gives the antenna impedances found for the delta and beach terrains.

The receiving antennas were located at least 40 feet from the equipment van. It has been found that the van has a negligible effect on the received signal at this distance for the antenna heights, frequencies, and polarizations used. The antennas themselves were spaced at least two wavelengths from each other.

B. Procedure

The basic measuring procedure consisted of recording the received signal obtained as the Xeledop was moved away or toward the receiver along a surveyed trail. This resulted in a recording of signal strength vs. separation of transmitter and receiver. In order to mark radial distance on the chart record, the following procedure was used: the intersections of several radii with the test trail were marked by stakes driven in the trail. The receiving-site operator was notified when the Xeledop carrier passed each of the trail markers, and the operator recorded the position information on the signal-strength record.

Care was exercised to ensure that the equipment was operating properly at all times. Several checks were made prior to, during, and after each experimental run. Before a run was started, the Xeledop was placed on a test stand located near the receiving antennas. It was then turned on and the receiver tuning was checked and the Xeledop's output was monitored by a wavemeter built into a test stand. This output reading was recorded in the operator's log. The Xeledop was then turned off and the chart recorder was calibrated. The test run was then made. Although the receiver is relatively stable, it was checked for drift during the run. Upon completion of the run, the Xeledop's radiated output was again monitored and recorded and, after the Xeledop was turned

off, the recorder was again calibrated. Prior to starting a series of runs, and after every three runs, the power output of each transmitter was measured using a Bird Model 6154 absorption wattmeter.

## IV DATA PROCESSING

The received-signal-vs.-distance data were recorded in analog form on a strip-chart recorder and the data from these records were scaled in order to present the results in a form suitable for easy interpretation.

It is pertinent at this point to make an examination of a strip-chart record before describing the data processing. Figure 4 is the beginning of a typical strip-chart record. On the left of this figure is the calibration made at the beginning of the run. This calibration staircase, together with the attenuator setting, gives the value of the received signal at a desired distance. To the right of the calibration is a vertical line that results from removing the calibrating signal generator, connecting the antenna to the reciever, and turning on the Xeledop. (The chart speed is also written along this line.) The line attenuator is also adjusted at this point, and Fig. 4 shows that 60 dB of attenuation was inserted at the beginning of this particular run. This large amount of attenuation is required to prevent overdriving the recorder by the strong signal received at the start of the run. The number with the prefix A indicates the amount of attenuation in the line.

The record of the AGC voltage consists of a generally decreasing (or increasing, as the transmitter is carried toward the receiving site) trace, as is shown in Fig. 4. Discontinuities in the trace caused by changes in the line-attenuator settings occur throughout the record. An example of such an attenuator change is shown near the right edge of Fig. 4. Twenty dB of attenuation were removed at this point, since the trace was nearing the lower end of recorder's dynamic range. The operator's note indicates 40 dB are still inserted in the system.

Along the top edge of Fig. 4 is a straight line with several vertical marks. These marks comprise the radial-range record which is made by the receiving-site operator when he receives the distance information over the auxiliary communications transceiver.

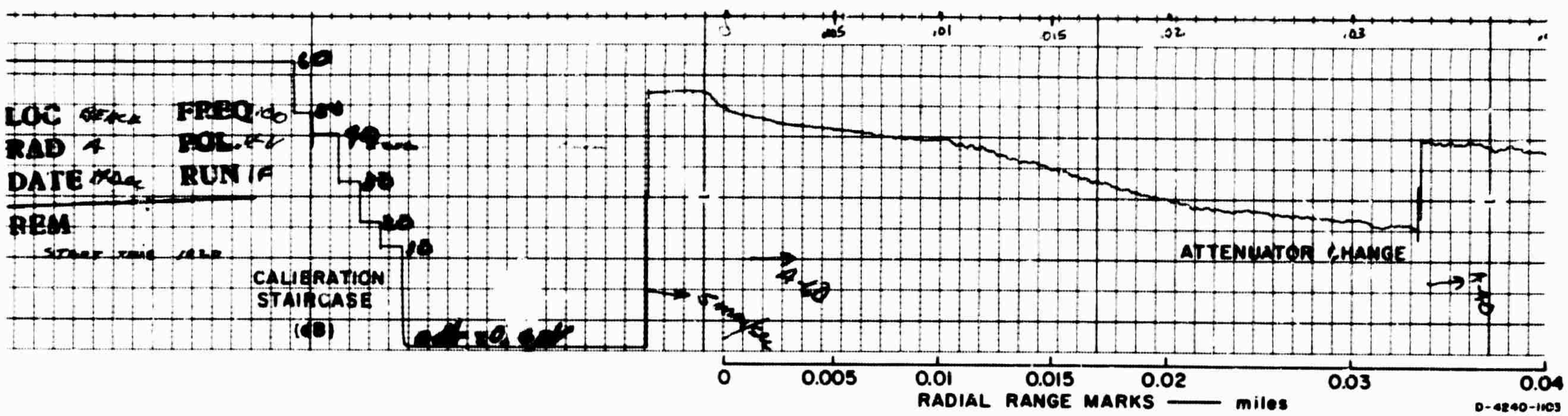


FIG. 4 STRIP-CHART RECORD

Conversion of the analog data to a useful presentation began with scaling of the record. The scaling process was one of determining the value of the received signal relative to some reference at each of several radial distances. The basic procedure was that of placing the calibration staircase alongside the signal trace at the desired distance and reading the amplitude of the trace. The signal level at the point in question was then found by adding the value of the line attenuation existing in the system in that instance to the signal amplitude determined by comparison of the signal trace with the calibration staircase.

Several distances were scaled to provide an accurate representation of the original data. The points actually scaled correspond to the radial intersections marked on the trail since distance at these intersections was most accurately known. At distances greater than 0.1 mile radial points were marked at intervals of 0.05 mile. At distances less than 0.1 mile radial points were marked at intervals of 0.01 mile in order to permit a finer representation of signal amplitude changes in this region.

Four runs were conducted for each measured combination of frequency and polarization. A run is defined as a one-way passage over the test trail. The time separation between two runs was small since two runs completed a round trip over the test trail. However, an effort was made to delay the start of the second two runs until several hours (sometimes as many as 24 hours) had elapsed since the completion of the first two runs. This was done to check the repeatability of the measuring system.

Data from the four runs were used in calculating the value of received signal strength at each distance plotted on the signal-strength-vs.-distance curves. For data from the open delta and open beach measurements, there was very little variation (signal fading), as illustrated by Fig. 4. In this case, the scaled values for each of the four runs at any radial distance point were averaged to give the value of signal strength. For data that exhibited large variations (foliaged terrain), a different scaling technique was required. In this case a small section of the record centered on the radial distance point in

question was scaled in order to increase the probability of bracketing the value of the received signal at that point. The segment centered at this point was chosen to provide enough values for an average but was not so wide that the terrain on one side of the radial distance trail marker would have more effect on the received signal than that on the other side of the marker. The interval chosen corresponded to a linear distance of about 14 feet on the trail.

The scaling interval was divided into six equal parts. The signal was scaled at the edge of each increment as well as at the radial point and at all of the peaks and dips in this interval. Scaling fading data in this manner for four runs often yielded 40 or more values, from which were derived the central tendency and variability of the data for the point in question.

The results are presented in terms of two commonly used descriptors: namely, the sample mean ($\bar{X}$) and the sample standard deviation ($\sigma$) of the received signal. These are given by:[4]

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - \bar{X})^2}{N - 1}}$$

where $X_i$ is the dB value of the received signal scaled from the record and N is the total number of values scaled near the radial point in question. It should be noted that for the open beach and open delta (non-fading data), only four values of the received signal are used to obtain the mean and standard deviation of the received signal at each radial intersection point. Although the sample is small it is felt that the application of these statistics is justified in view of small differences found for these relatively non-fading cases.

The median of the values in a scaling interval was compared with the mean of these values, for many intervals. It was found that the median and mean were nearly equal, indicating a normal distribution for the data.

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# V TERRAIN DESCRIPTIONS

## A. Delta

The open delta test site was a large, open area of rice paddies. This area is criss-crossed by several one-lane roads, one of which was used as a test trail. These roads are constructed of a paddy-earth fill with a surface coating of laterite. At the time of the delta tests (17-19 November, 1965) the water level in the paddies was about 2 feet below the surface of the road. The characteristic features of this site can be seen in Fig. 1.

## B. Beach

The beach terrain tests were conducted along the east coast of the Gulf of Thailand during 13-21 December 1965. The site consists of a sandy area that extends about 1/2 mile inland. For the first 400 feet inland, the beach is relatively open and free of foliage. Beyond 400 feet the area is covered with dense, short growth of shrubs, bushes and other small plants. There are a few widely separated trees growing in this area. Figures 5 and 6 are views of the beach terrain. Figure 7(a) is a drawing of the test area shown in the aerial photographs [Figs. 7(b), (c), (d)]. Three test trails were measured at the beach. One of these, which is denoted as open beach [Fig. 7(c)], was located parallel with the ocean in the region free of foliage. The other two trails, denoted as foliaged beach A [Fig. 7(b)] and foliaged beach B [Fig. 7(d)], were located deep in the foliage that bordered the open beach.*

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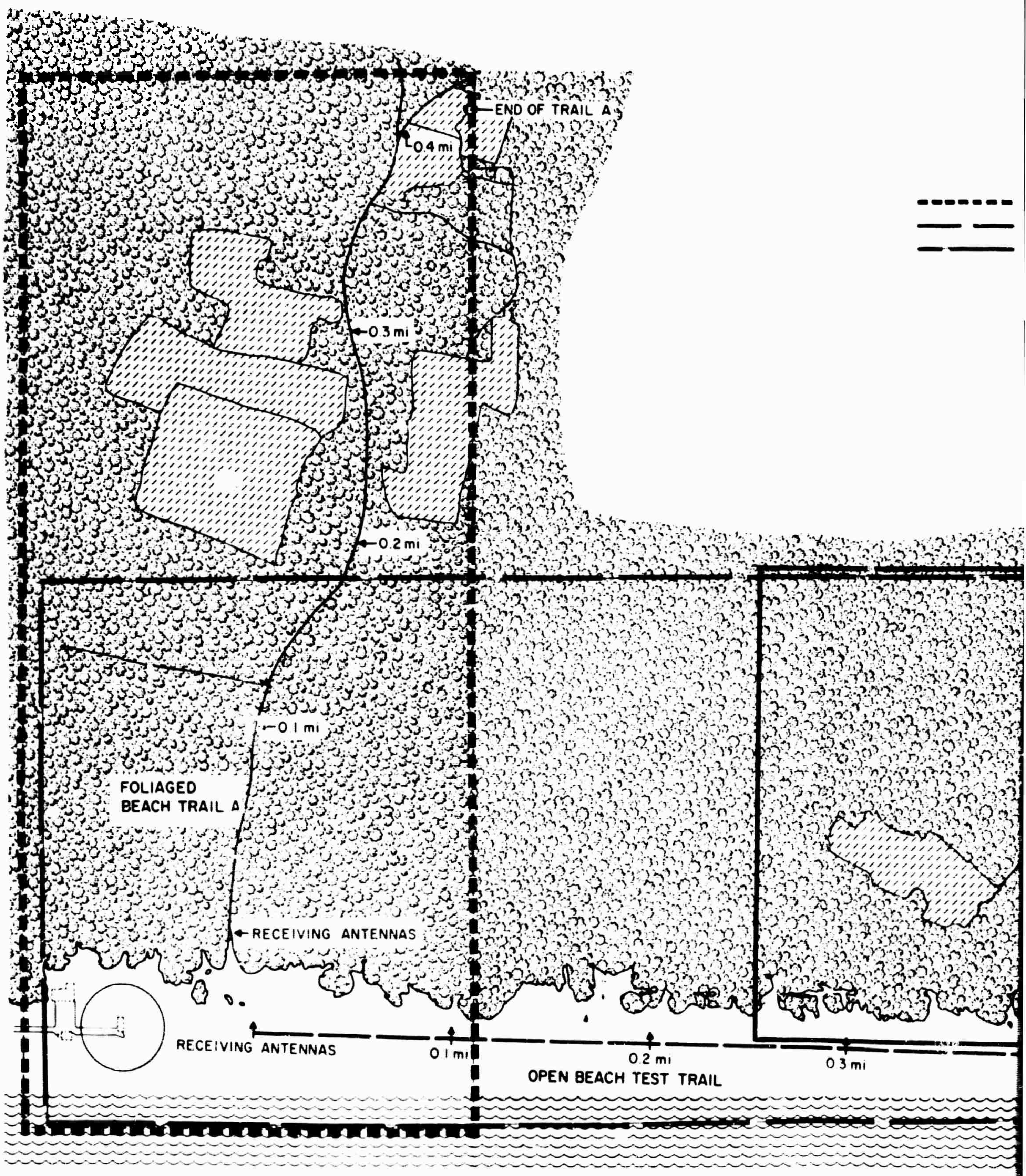
*A detailed report of foliage and soil measurements made by the MRDC Environmental Sciences Division is given in Appendix B.


FIG. 5 OPEN BEACH TERRAIN

FIG. 6 FOLIAGED BEACH TERRAIN


END OF TRAIL A
0.4 mi
0.3 mi
0.2 mi
0.1 mi
FOLIAGED
BEACH TRAIL A
RECEIVING ANTENNAS
RECEIVING ANTENNAS
0.1 mi
0.2 mi
0.3 mi
OPEN BEACH TEST TRAIL

A

AREA OF FIG. 7(b), FOLIAGED BEACH TRAIL A
AREA OF FIG. 7(c), OPEN BEACH
AREA OF FIG. 7(d), FOLIAGED BEACH TRAIL B

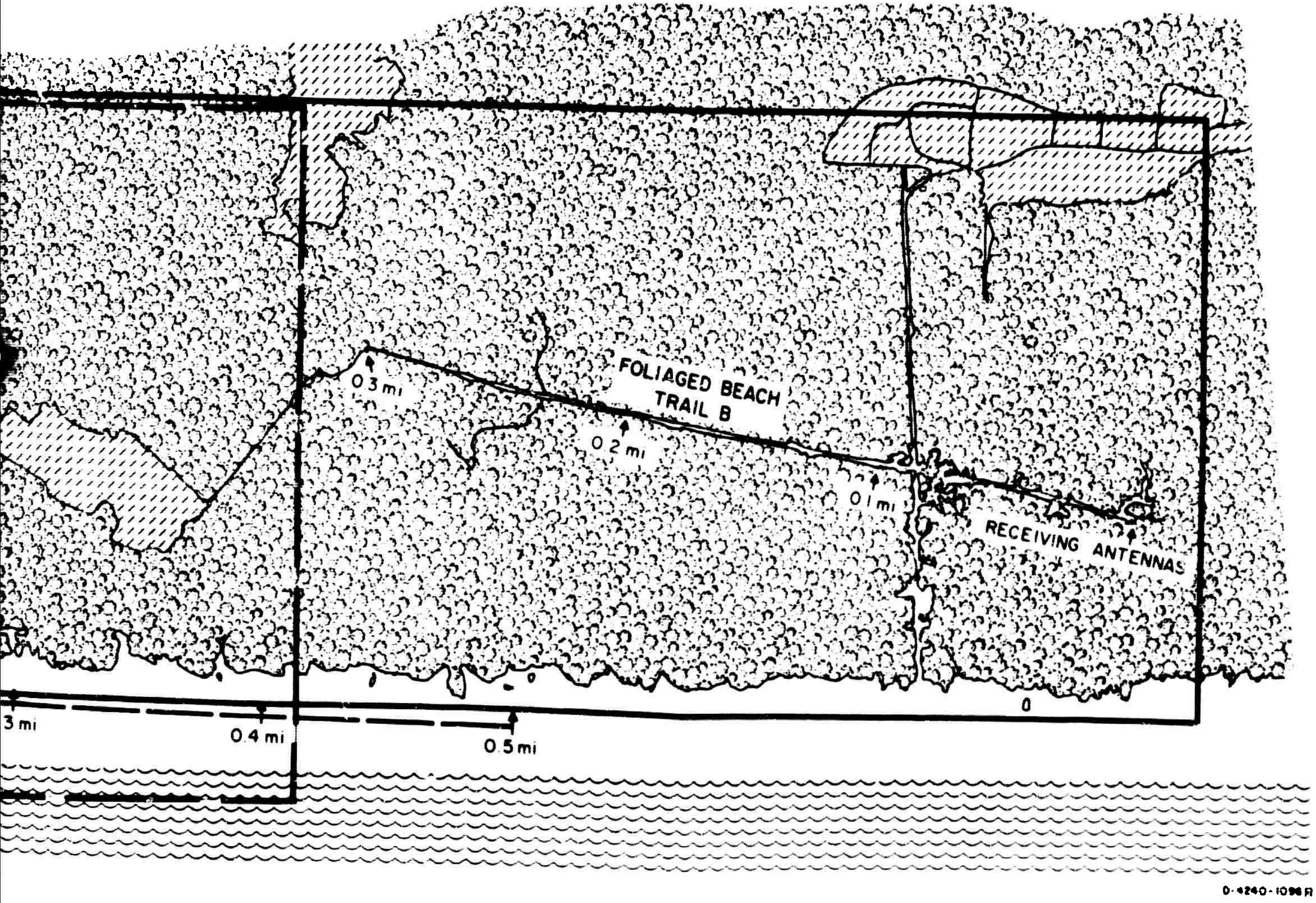



FIG. 7(a) DRAWING OF BEACH TEST AREA

END OF TRAIL
0.4 mi

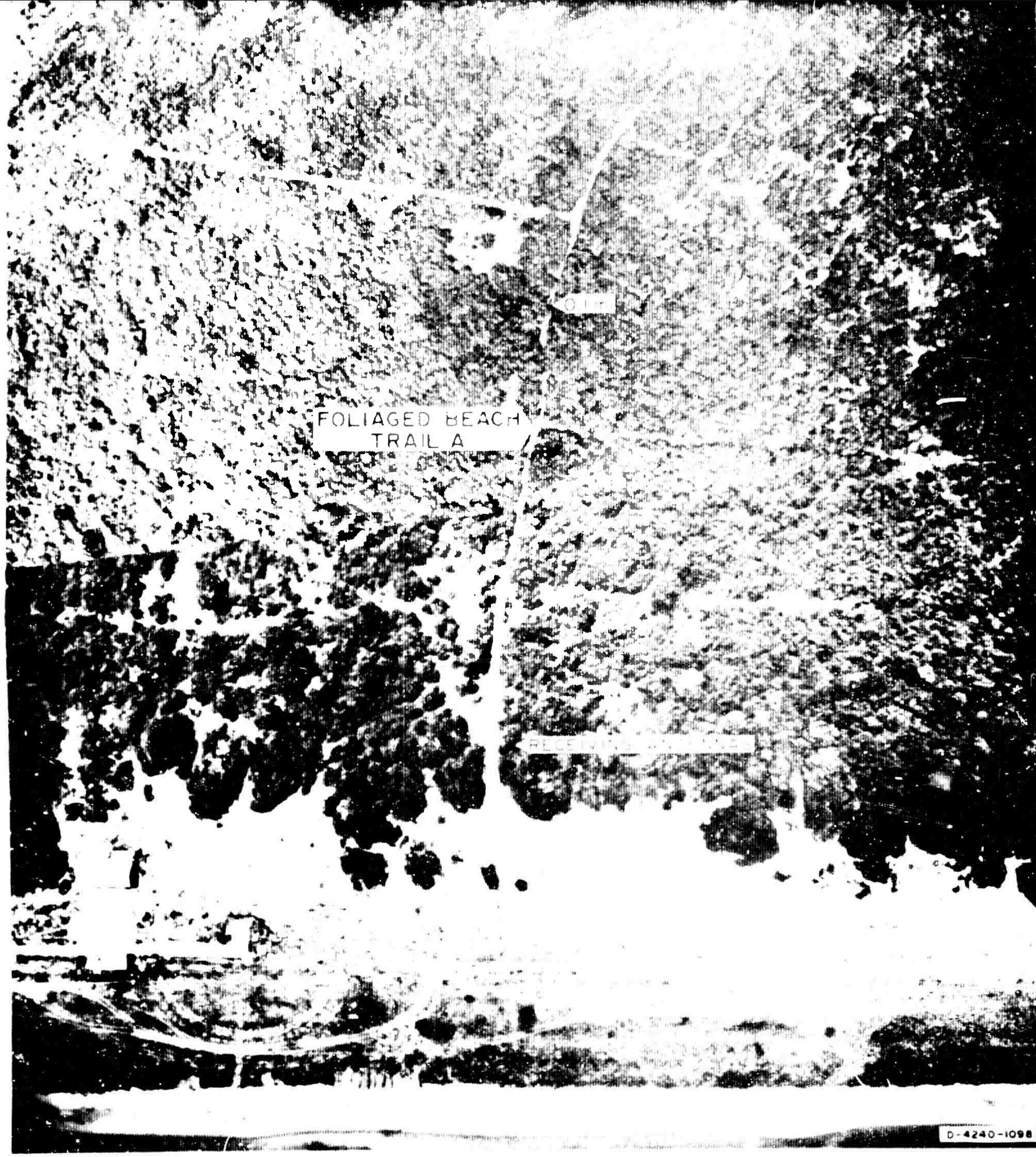
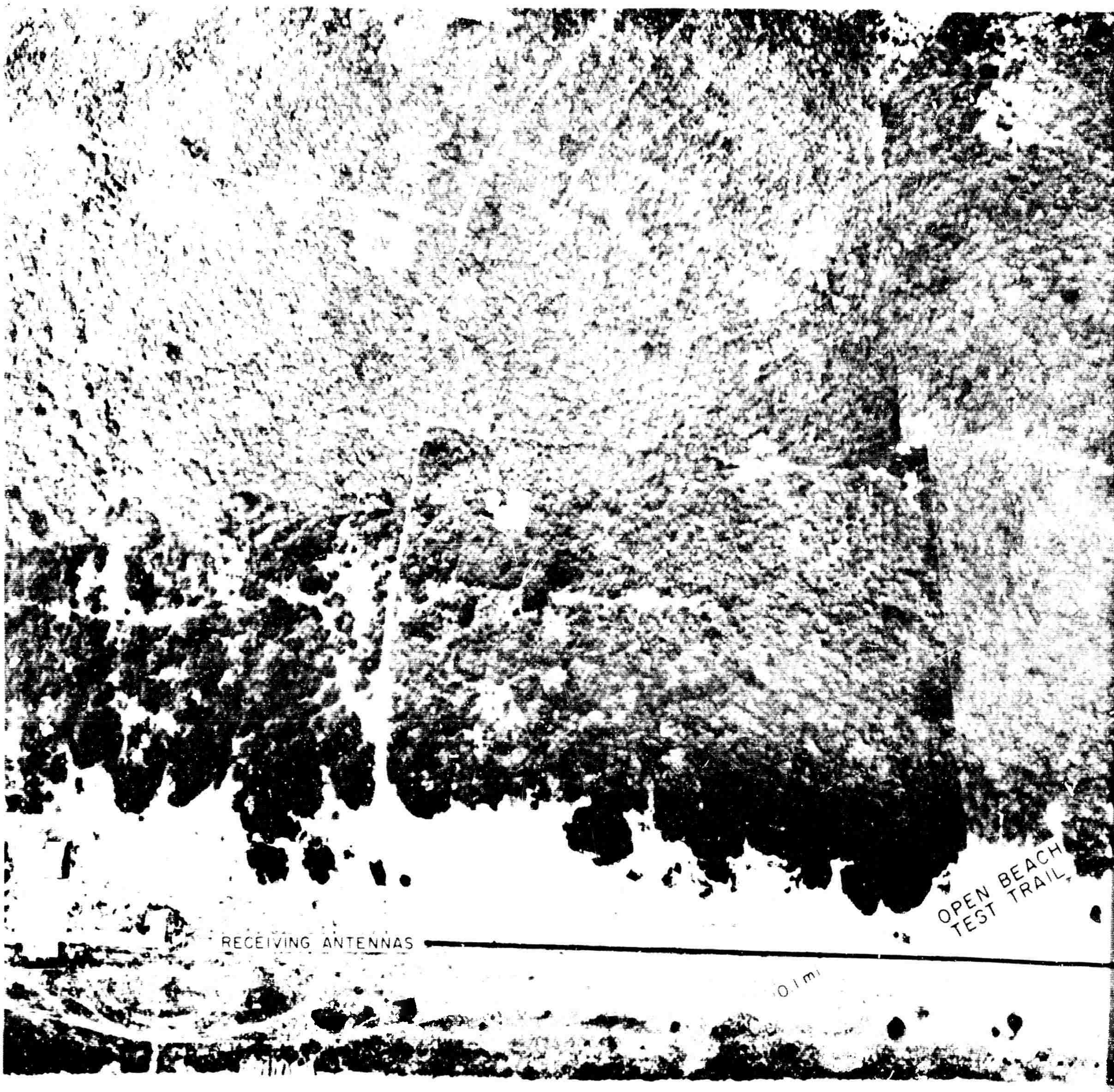



FIG. 7(b) FOLIAGED BEACH TRAIL A

B




A

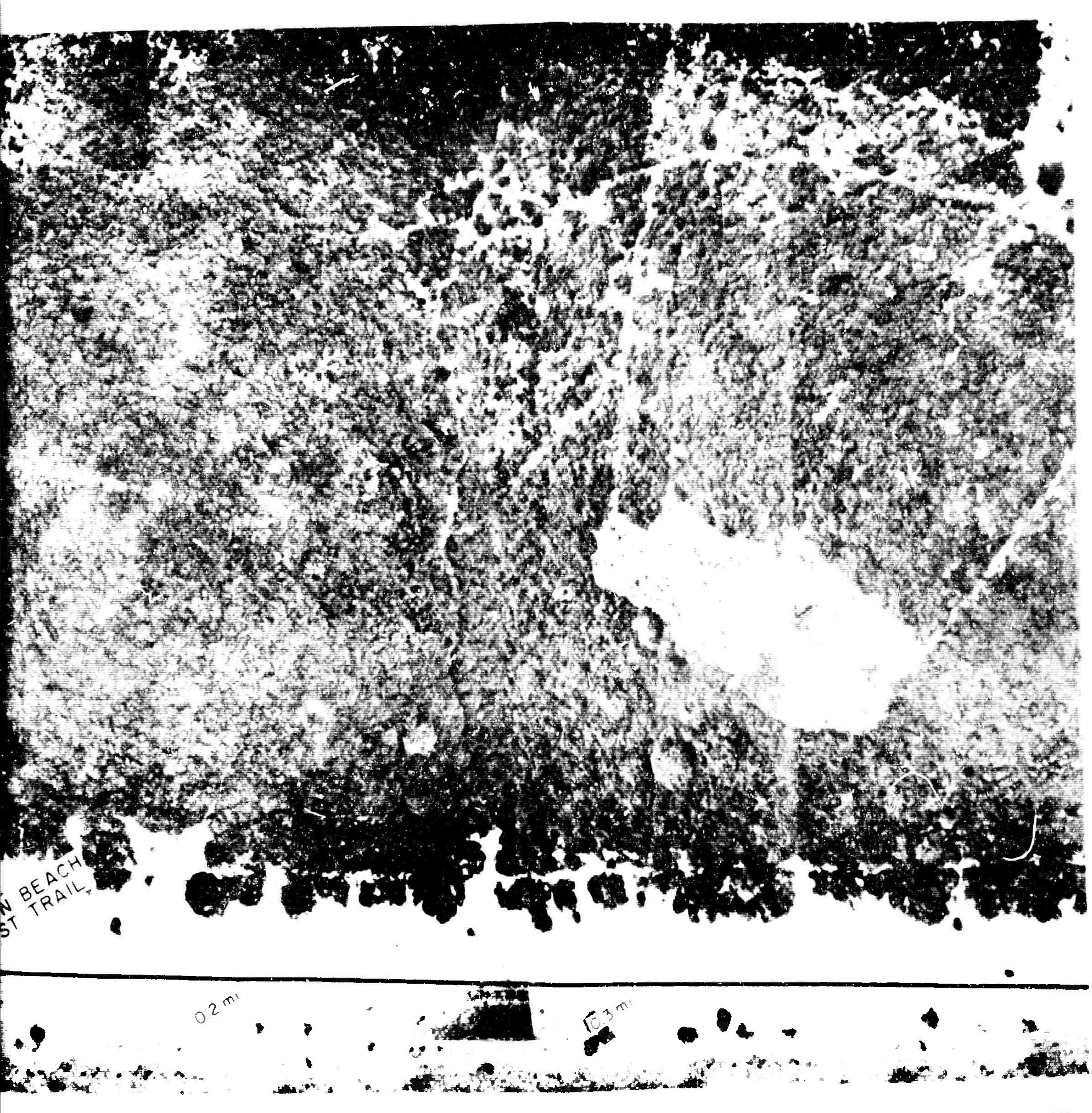



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FIG. 7(c) OPEN BEACH

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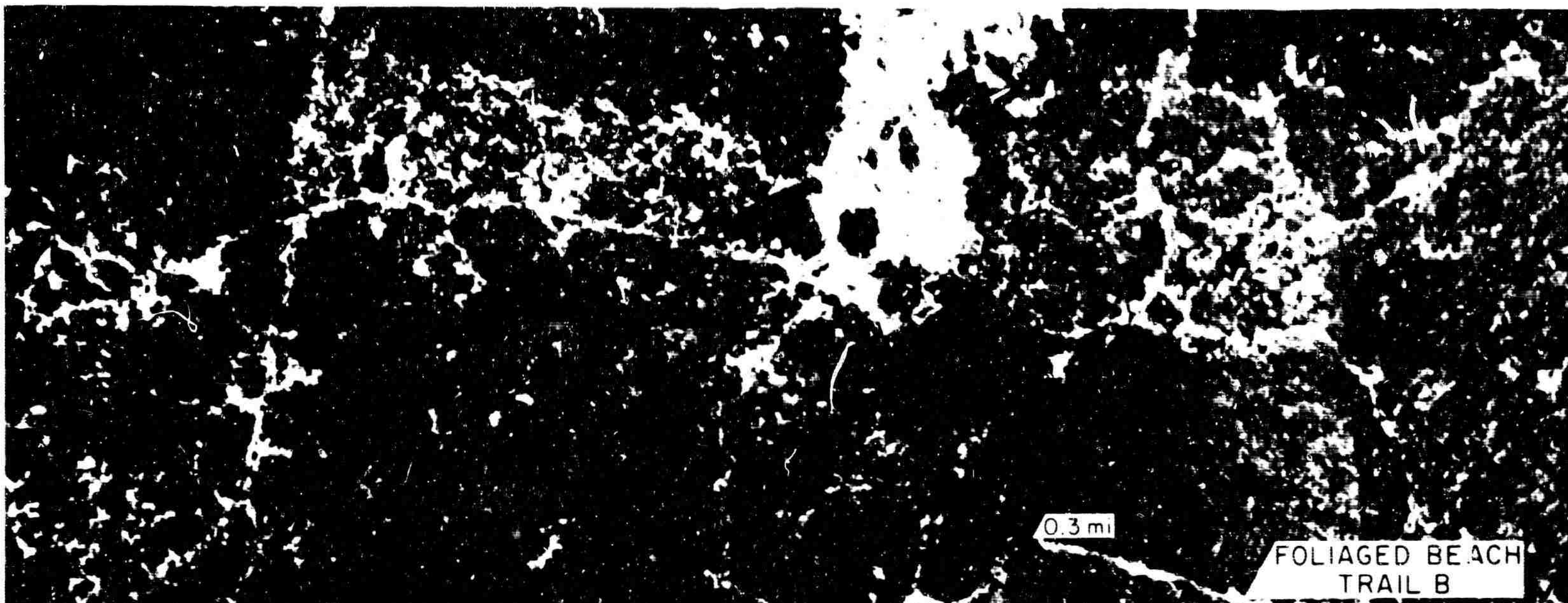


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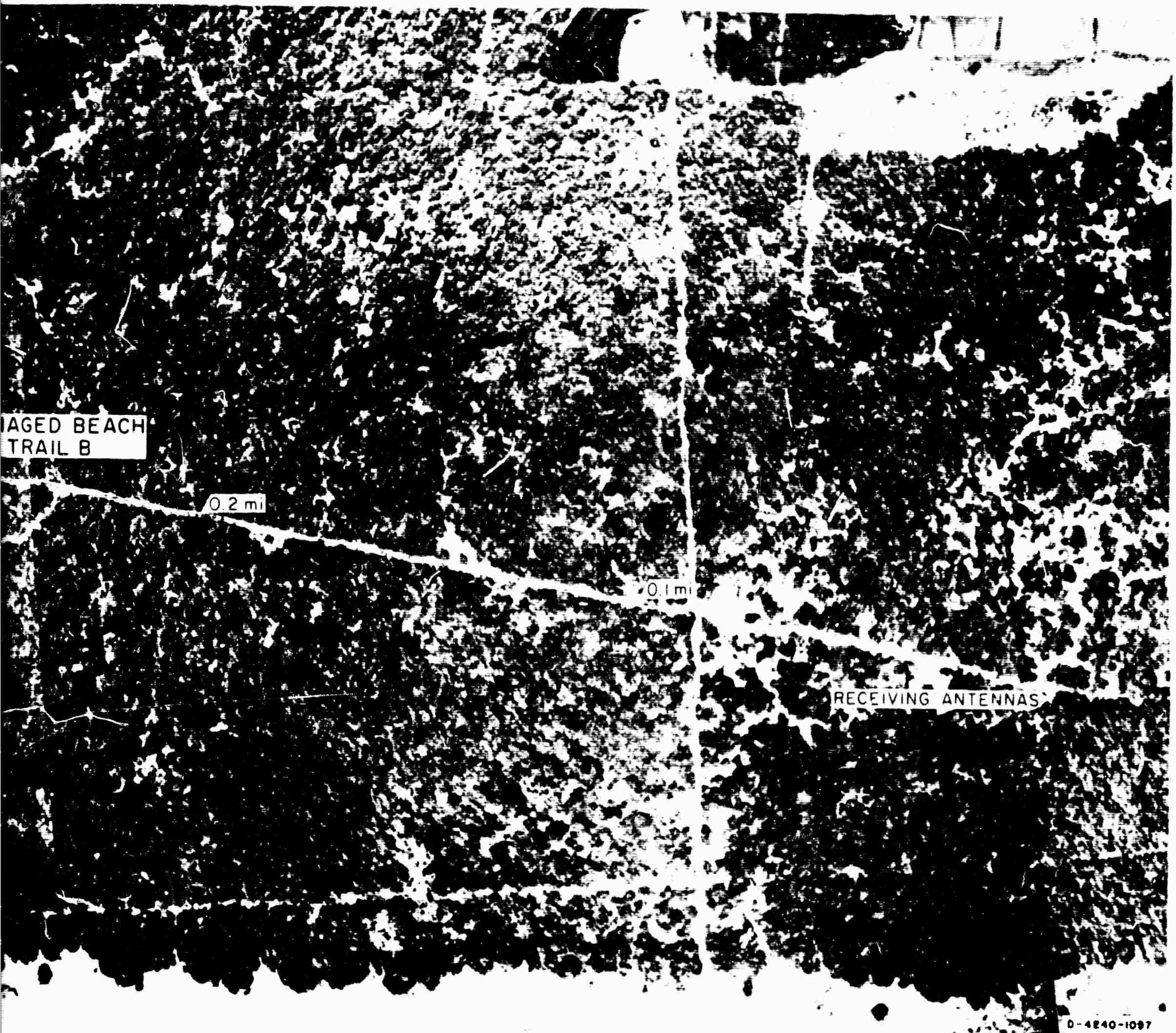


FIG. 7(d) FOLIAGED BEACH TRAIL 3

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## VI RESULTS

Measurements of signal strength as a function of distance between the transmitter and receiver for open delta, open beach, and foliaged beach were made during the course of the work described in this report. Three frequencies (50, 75.1,* and 100 MHz), and two antenna polarizations [horizontal-to-horizontal (H-H) and vertical-to-vertical (V-V)] were employed.

Results of these measurements are presented in two sets of curves. The first set--basic curves representing the results of individual measurements--give the mean value and the two-sigma range of the received signal versus distance for each frequency/polarization/terrain combination measured. For example Fig. 8 gives the basic curves for horizontal polarization over open delta for 50, 75, and 100 MHz. The second set of curves consists of comparison curves. This set compares the test results by frequency, polarization, and terrain in order to facilitate the interpretation and understanding of the results.†

The basic and comparison curves are presented in the following order:

BASIC CURVES

Open Delta: Figures 8 and 9

Open Beach: Figures 10 and 11

Foliaged Beach A: Figures 12 and 13

Foliaged Beach B: Figures 14 and 15

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*The frequency of 75.1 MHz is used, since 75 MHz is internationally reserved for use as an aeronautical beacon. This frequency will be referred to in the remainder of the report as 75 MHz.

†Figure 16 is an example of a comparison curve.

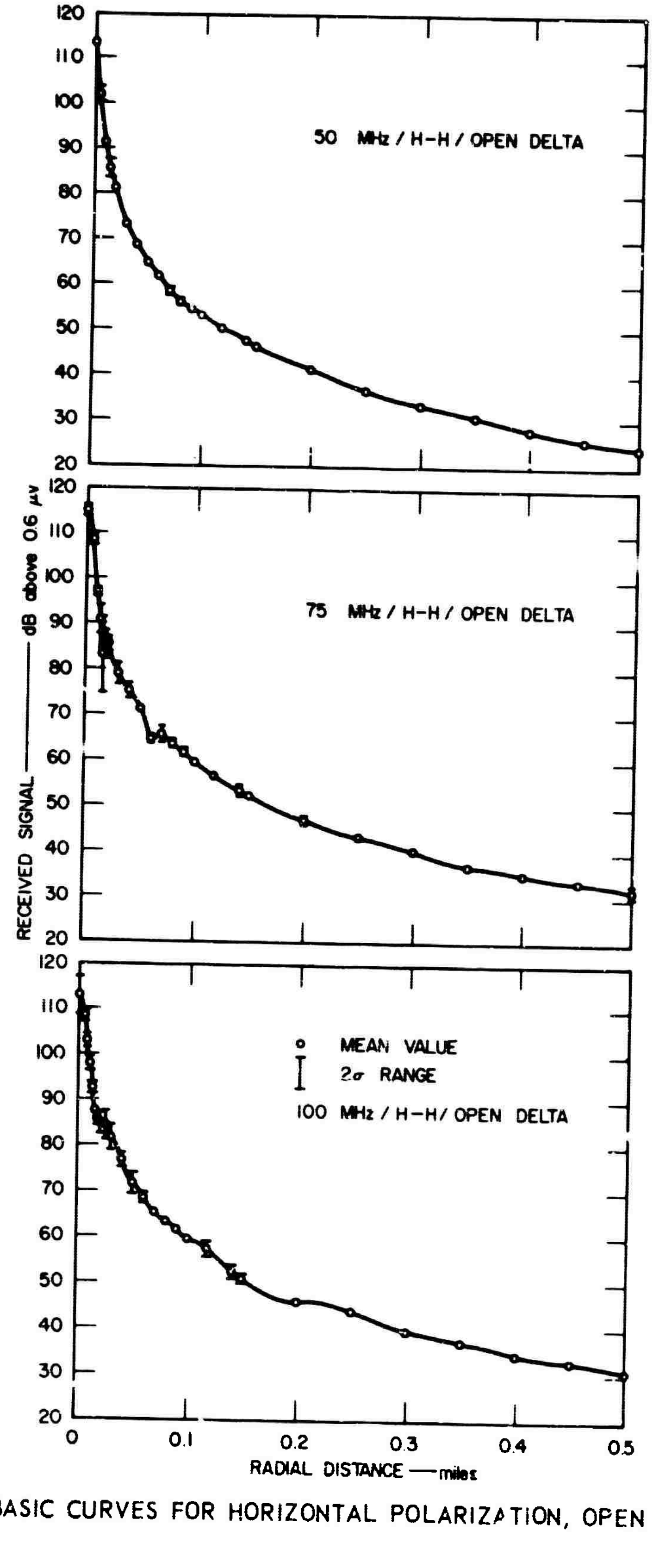



FIG. 8 BASIC CURVES FOR HORIZONTAL POLARIZATION, OPEN DELTA

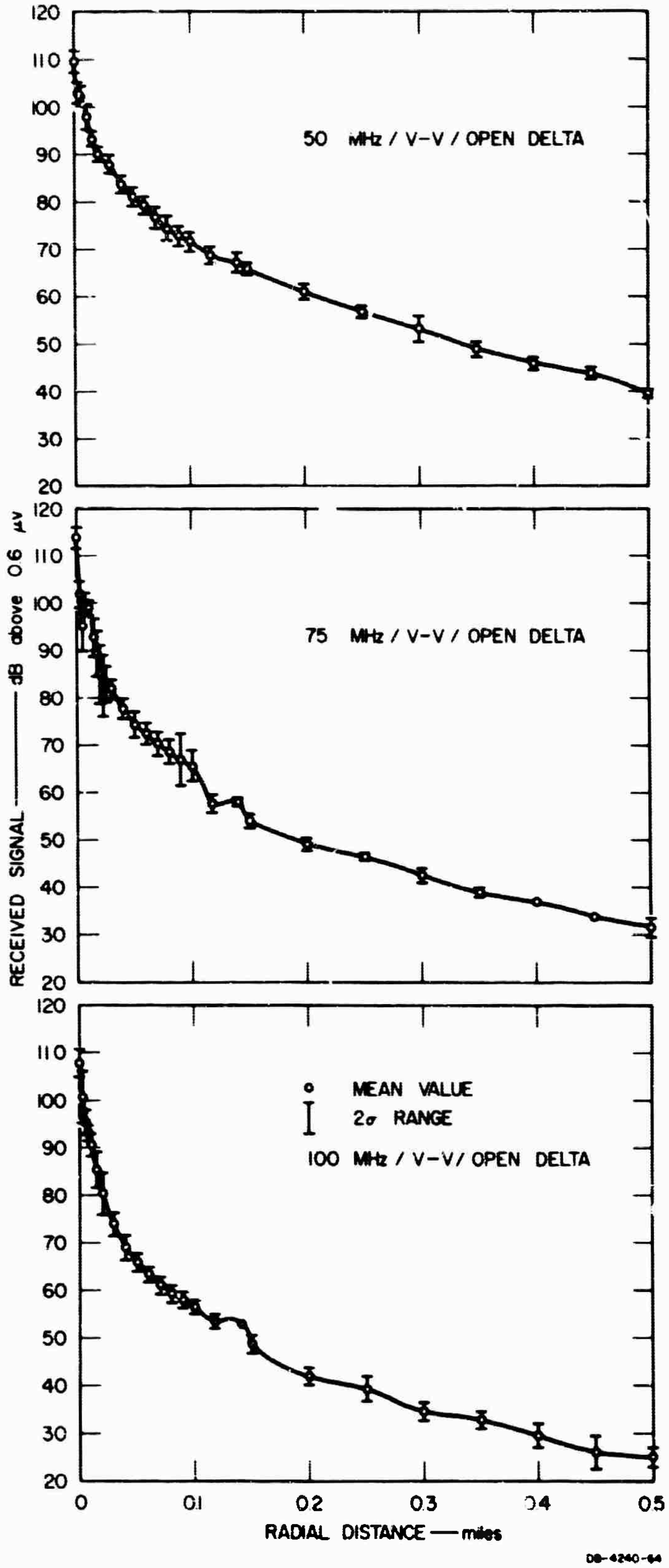



FIG. 9 BASIC CURVES FOR VERTICAL POLARIZATION, OPEN DELTA

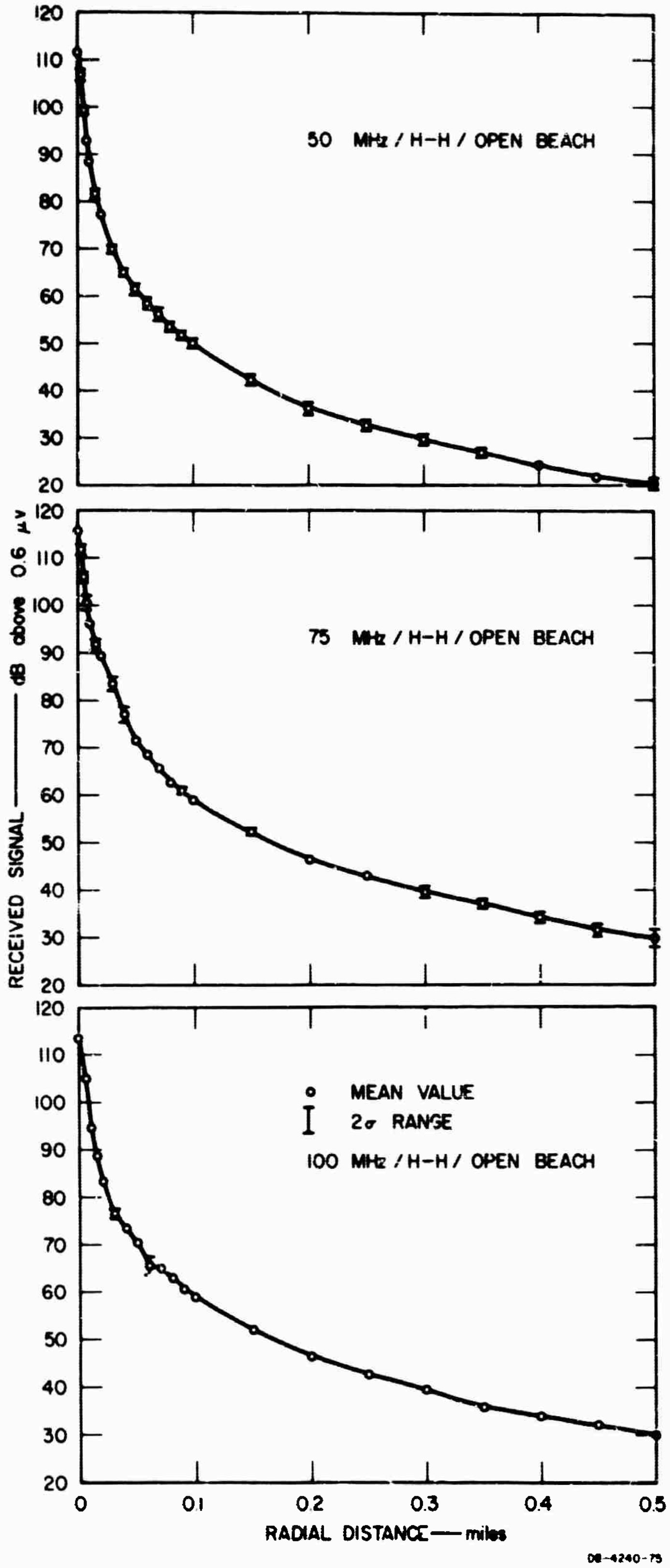



FIG. 10 BASIC CURVES FOR HORIZONTAL POLARIZATION, OPEN BEACH

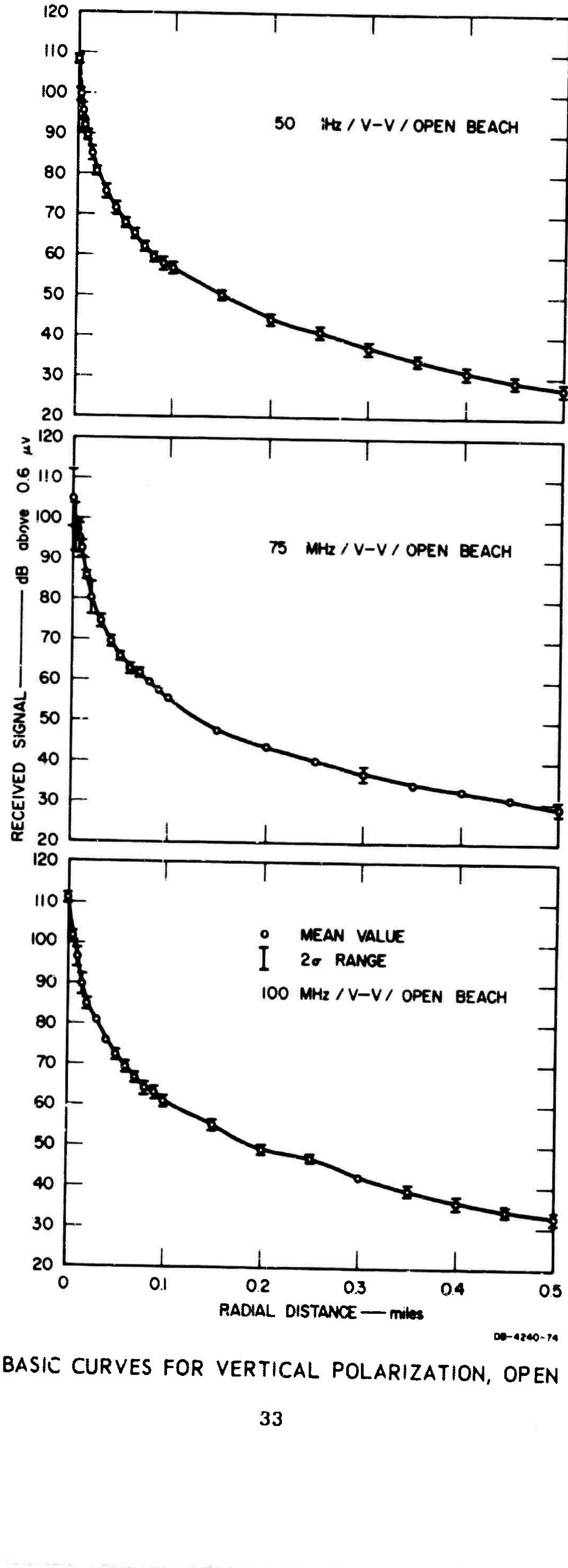



FIG. 11 BASIC CURVES FOR VERTICAL POLARIZATION, OPEN BEACH

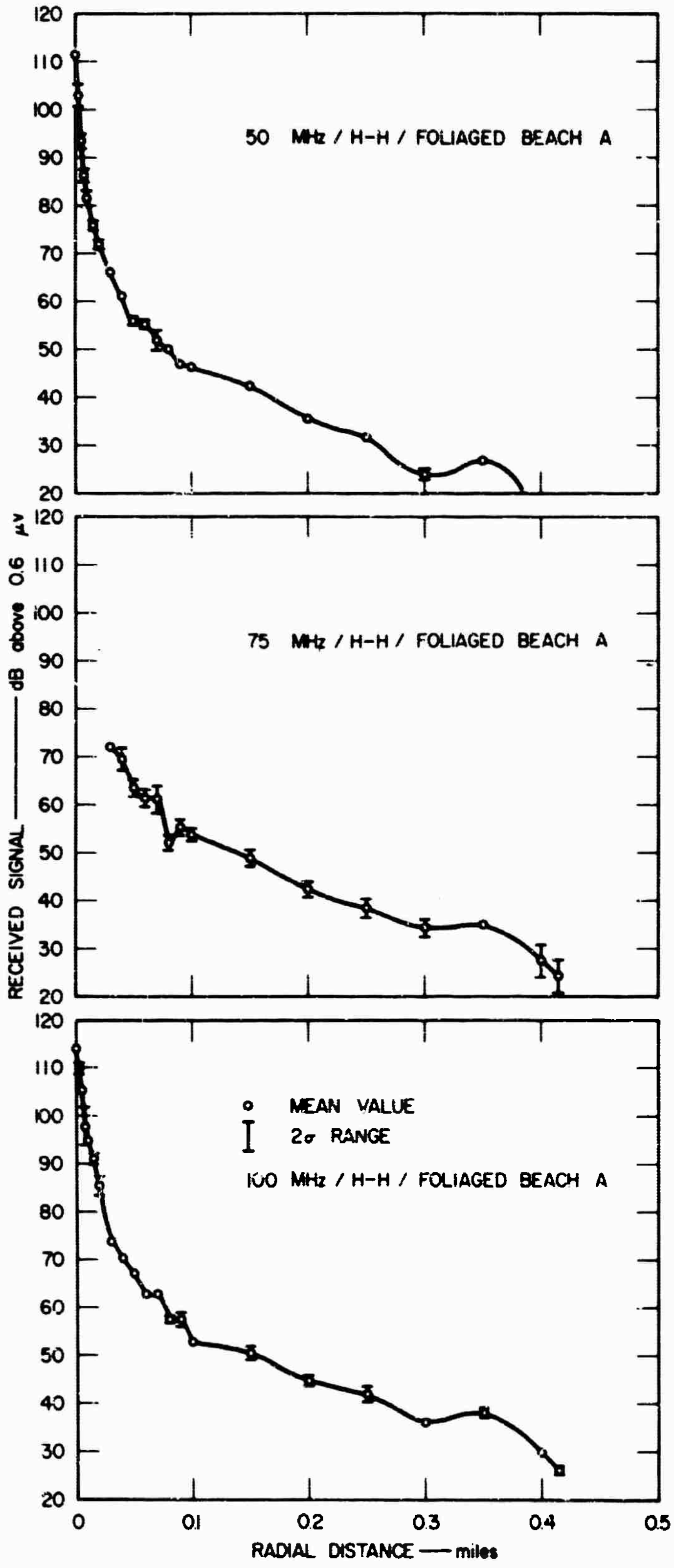



FIG. 12 BASIC CURVES FOR HORIZONTAL POLARIZATION, FOLIAGED BEACH A

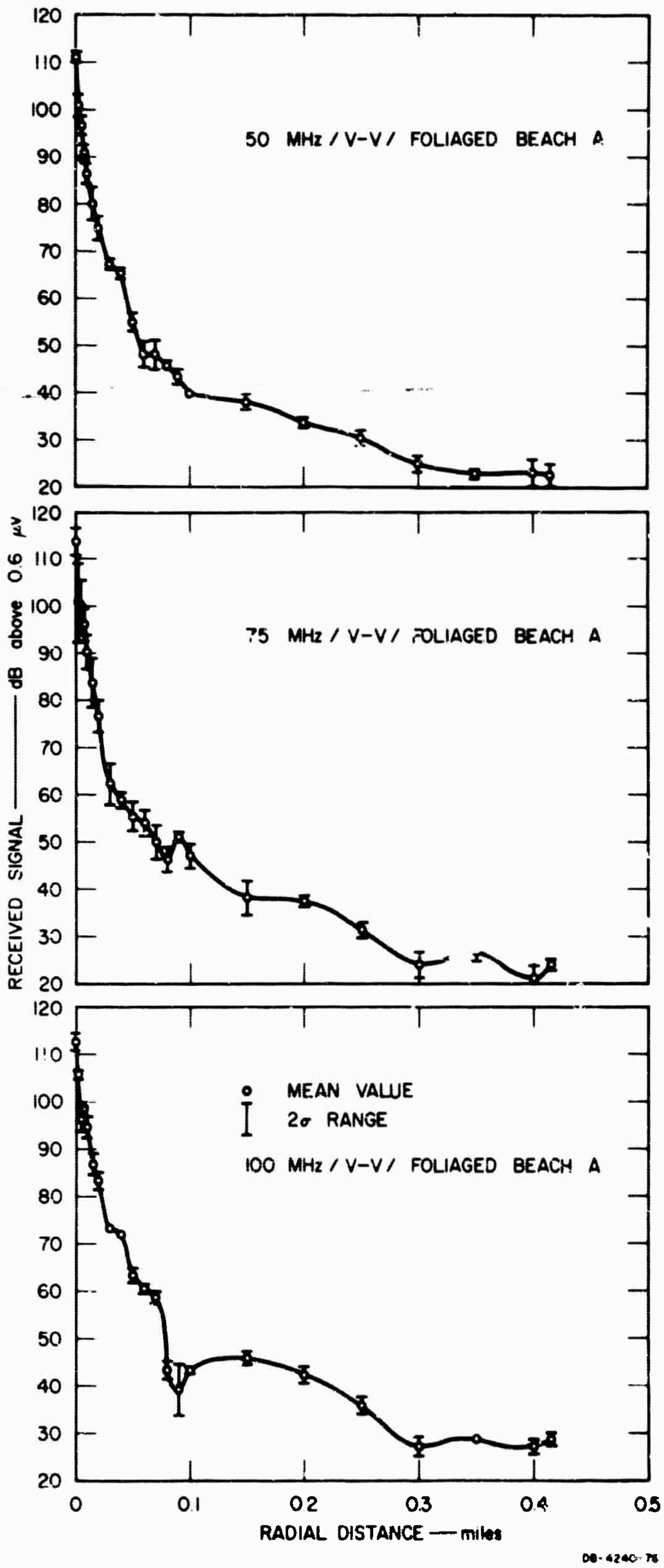



FIG. 13 BASIC CURVES FOR VERTICAL POLARIZATION, FOLIAGED BEACH A

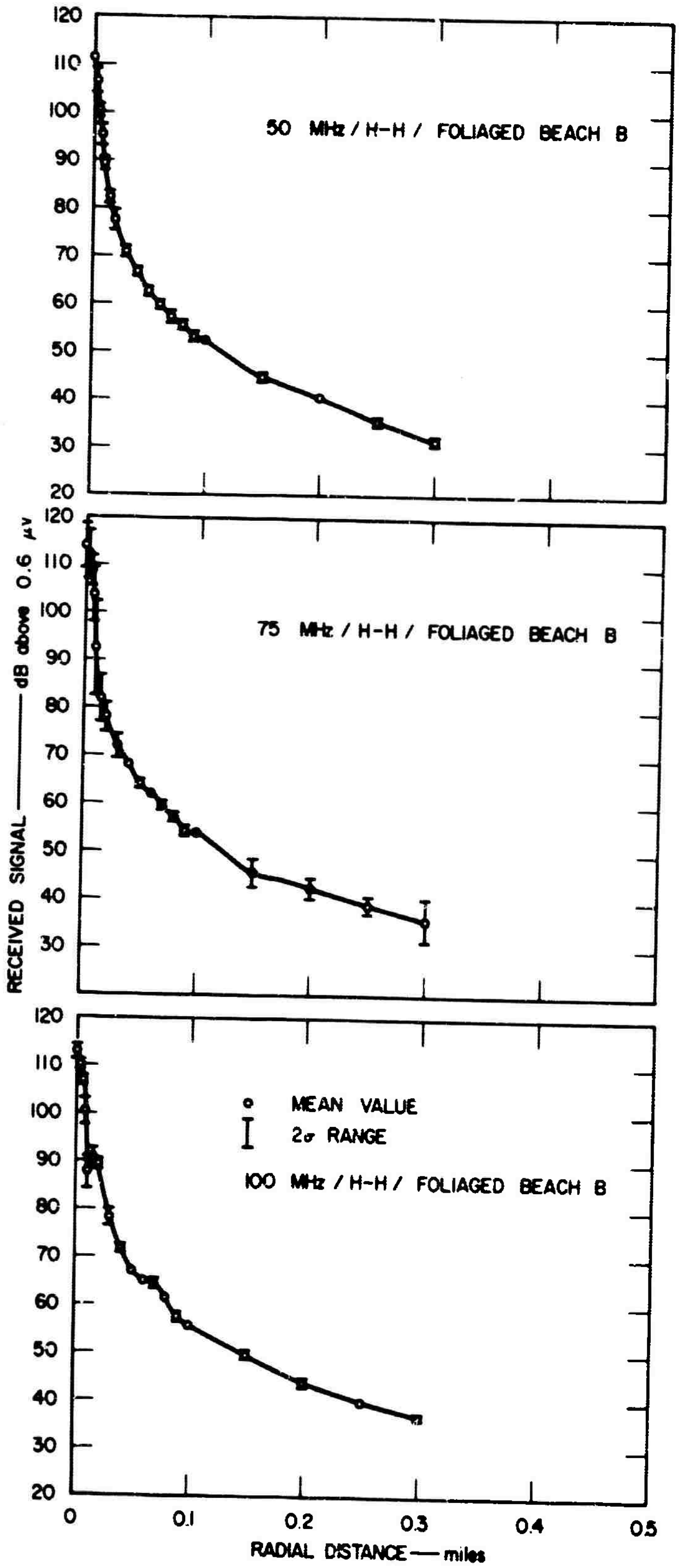



FIG. 14 BASIC CURVES FOR HORIZONTAL POLARIZATION, FOLIAGED BEACH B

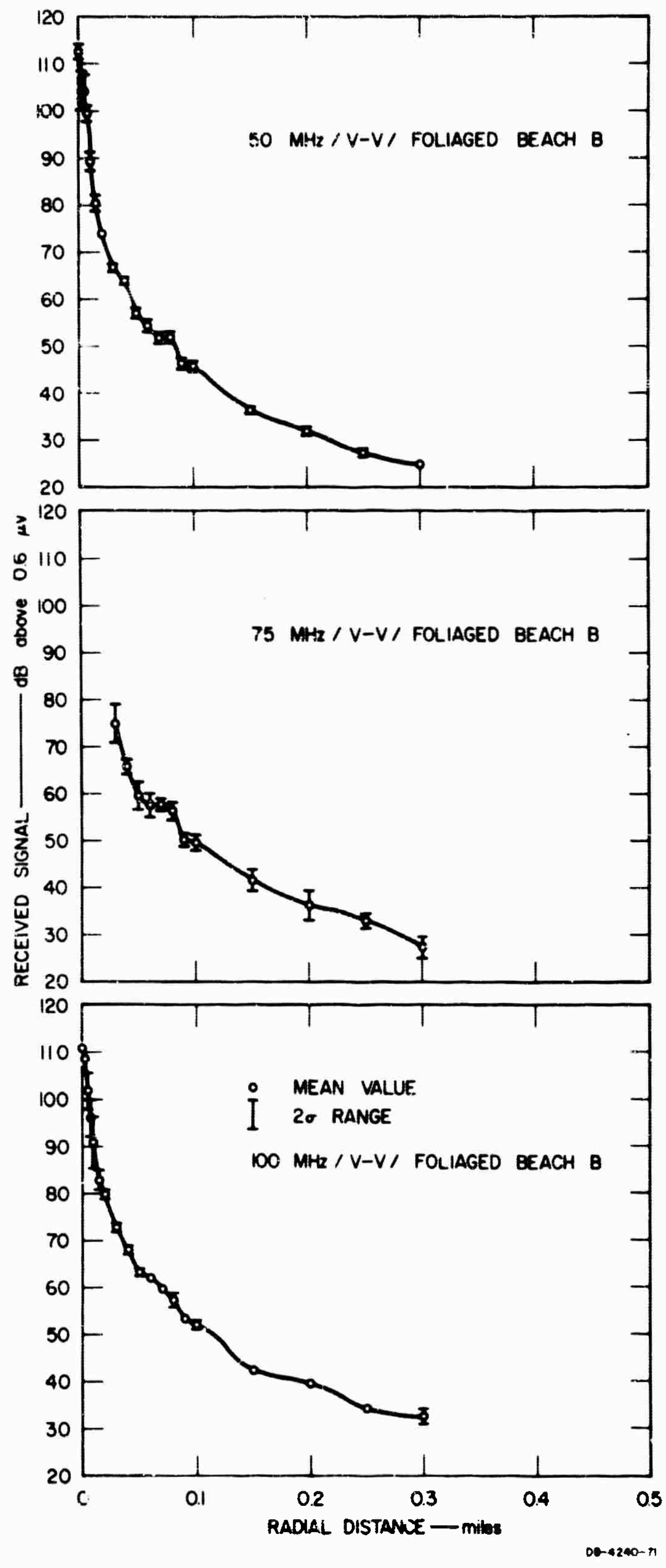



FIG. 15 BASIC CURVES FOR VERTICAL POLARIZATION, FOLIAGED BEACH B

## COMPARISON CURVES

Frequency Comparisons: Figures 16 through 19

Polarization Comparisons: Figures 22 and 23

Terrain Comparisons: Figures 24 and 25.

Several characteristics of the data plots should be pointed out. For example, it will be noted that the two-sigma range of signal variation is missing in some of the basic curves. In those cases the two-sigma range is ess than 2 dB, which is the diameter of the circle representing the mean value of the signal strength. The effect of scaling radial points more frequently at distances less than 0.1 mile (every 0.01 mile), and every . 15 mile at greater distances, has an effect on the appearance of the curves. The smaller interval results in a more detailed curve showing more variations while the greater interval causes a curve to appear smoothed. Thus, the change in apparent variation of the mean value curves at 0.1 mile should not be interpreted as a measured effect.

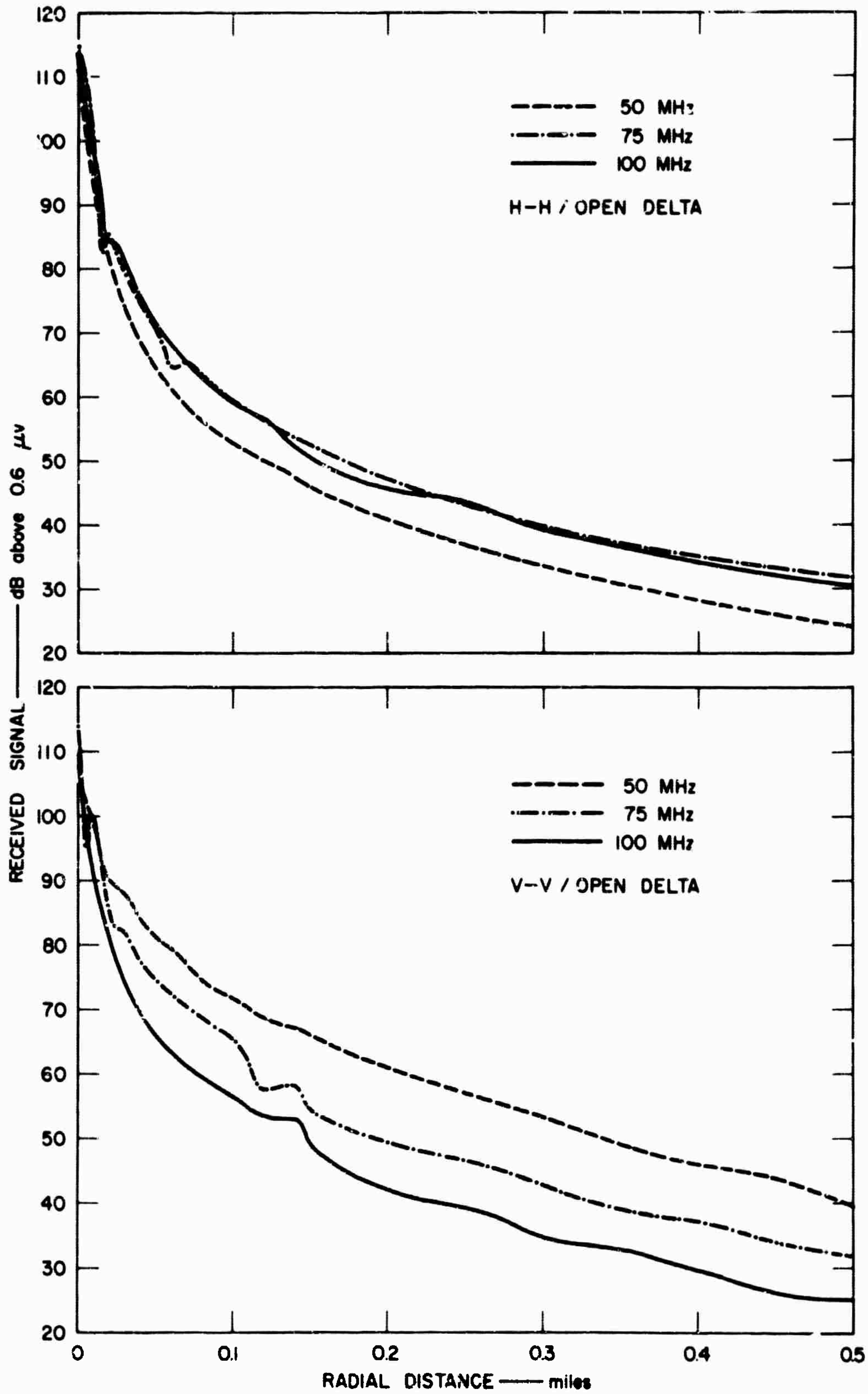



FIG. 16 FREQUENCY COMPARISONS FOR OPEN DELTA

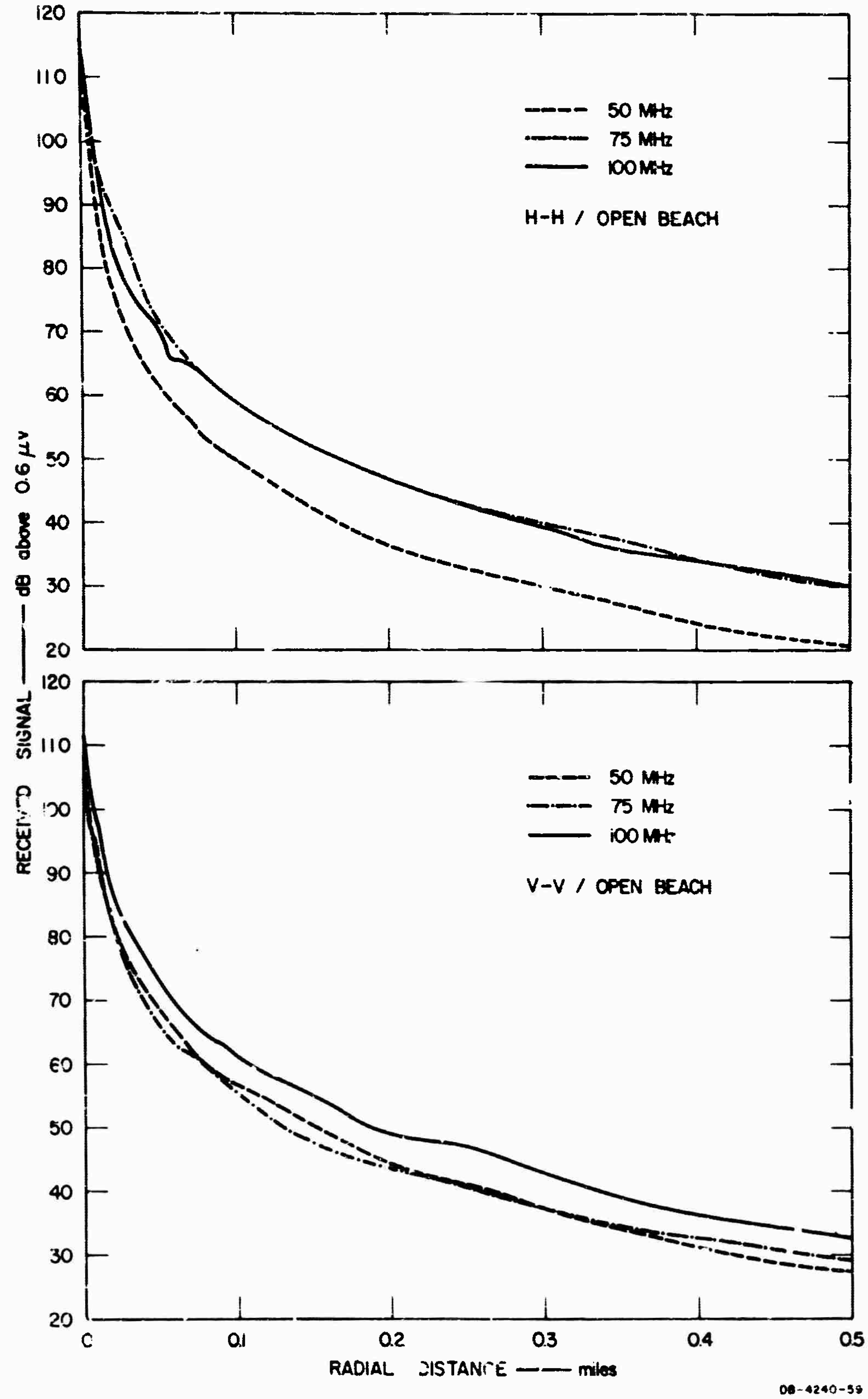



FIG. 17 FREQUENCY COMPARISONS FOR OPEN BEACH

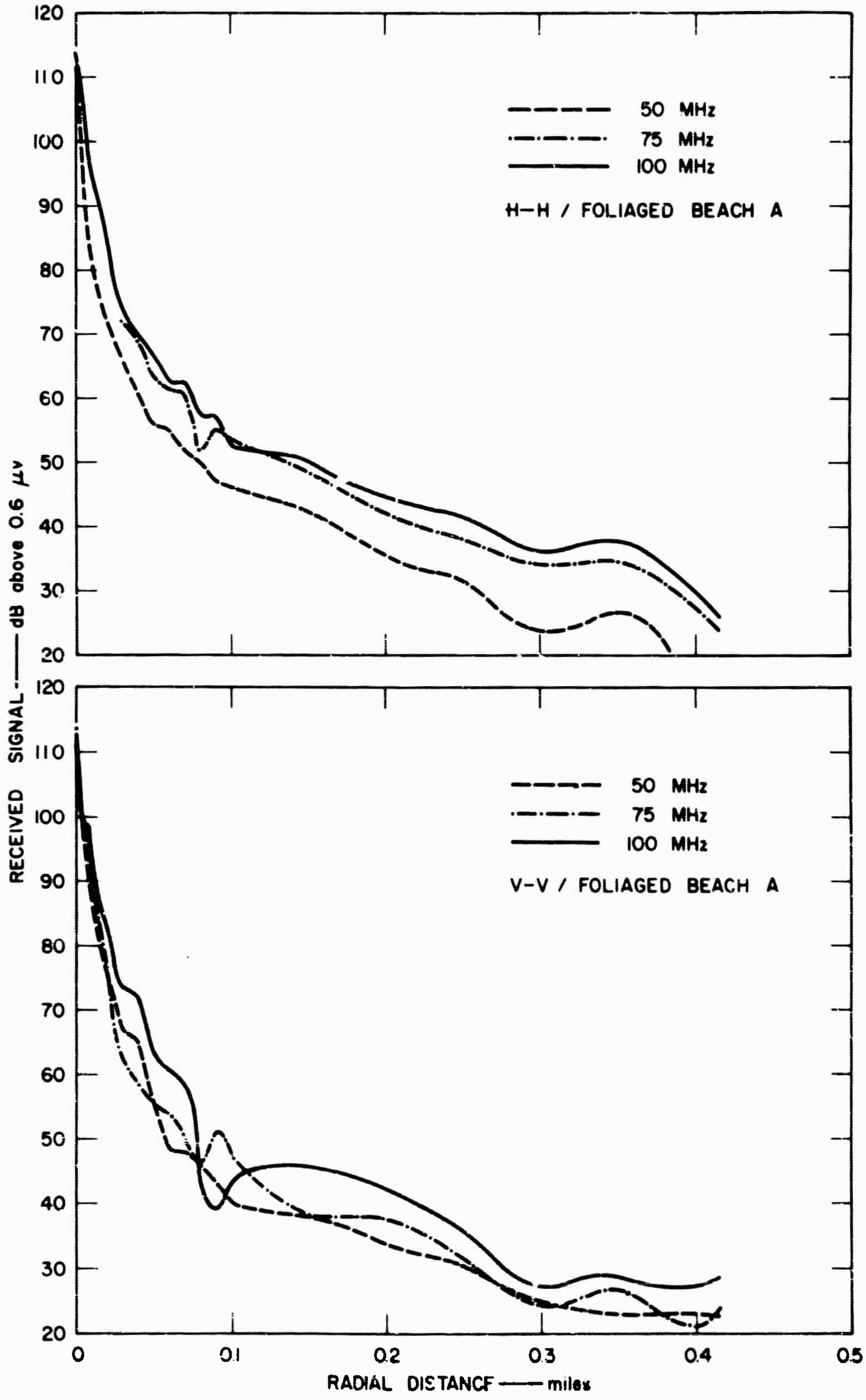



FIG. 18 FREQUENCY COMPARISONS FOR FOLIAGED BEACH A

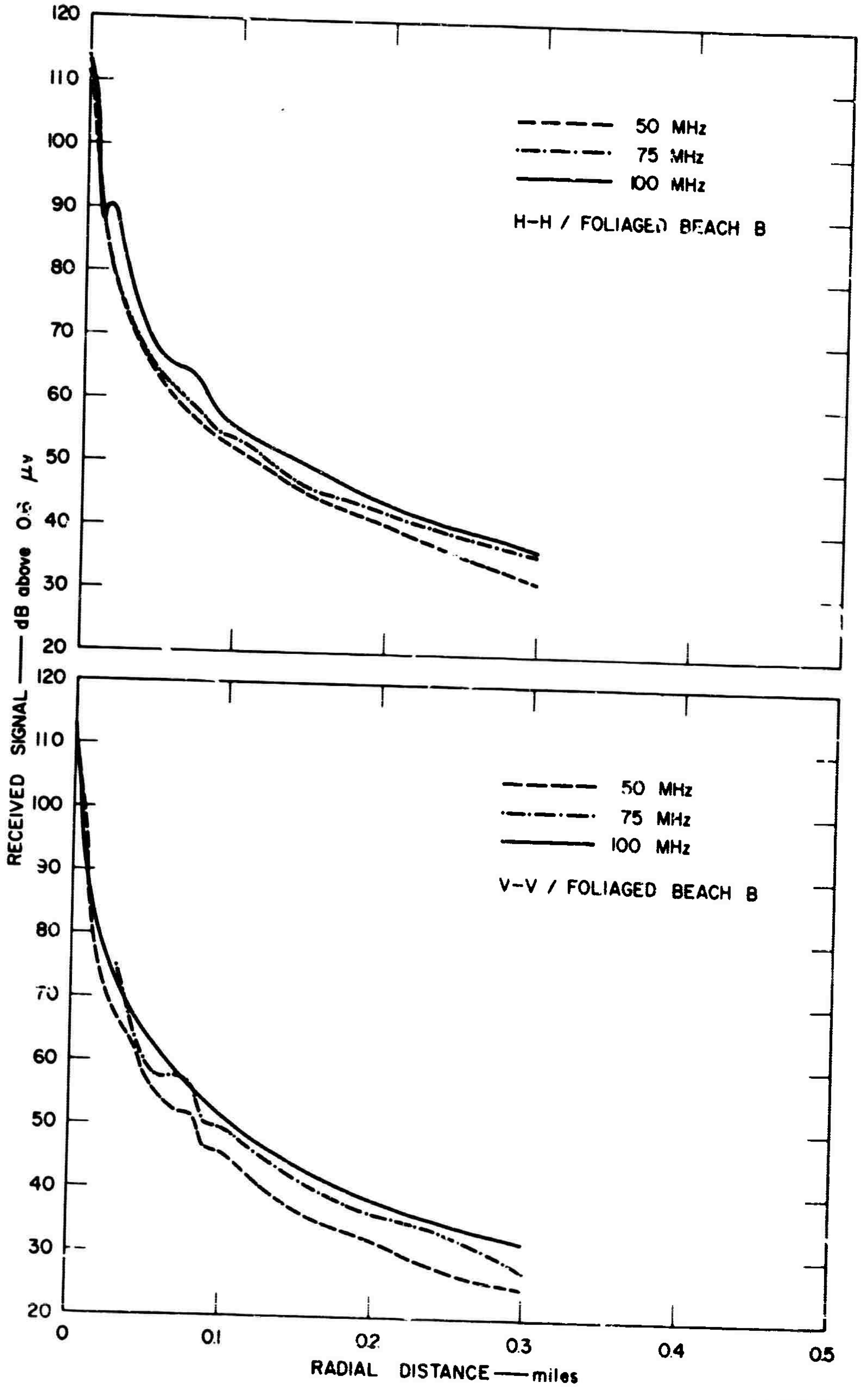



FIG. 19 FREQUENCY COMPARISONS FOR FOLIAGED BEACH B

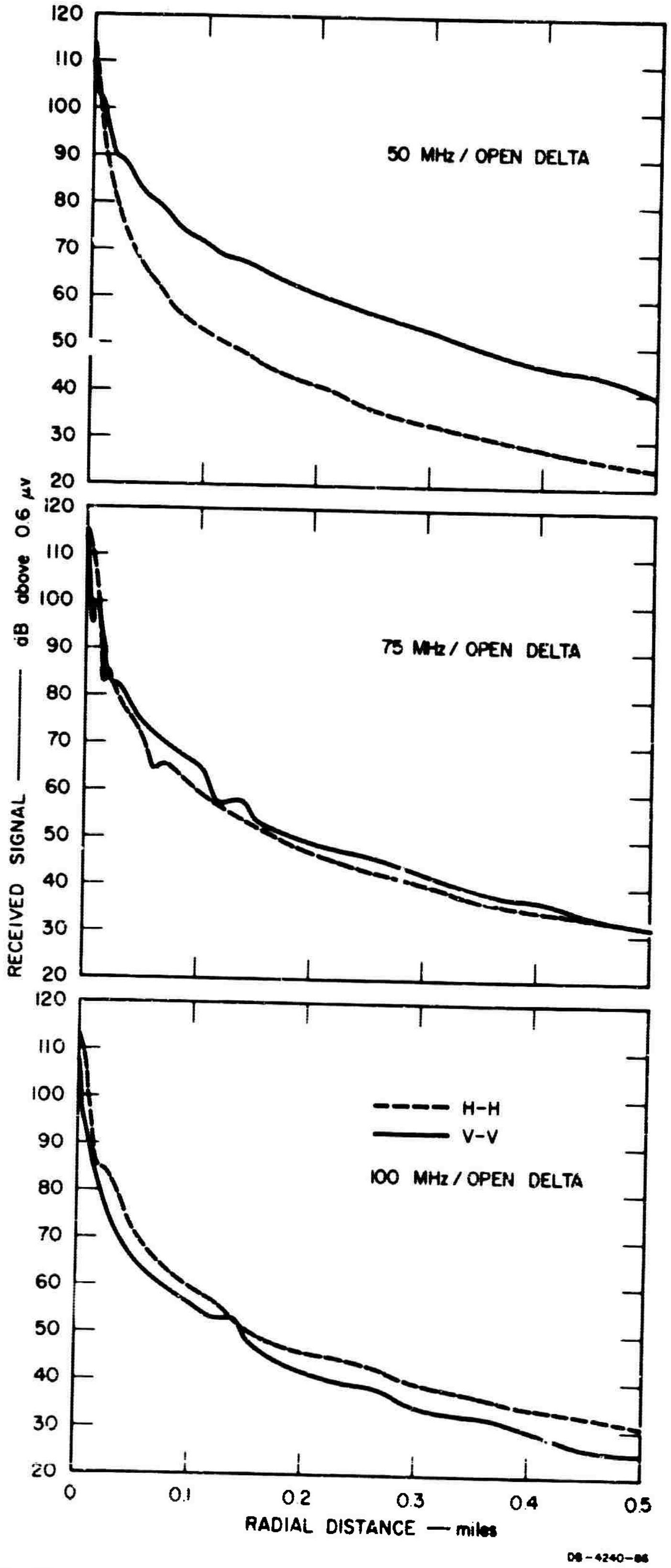



FIG. 20 POLARIZATION COMPARISONS FOR OPEN DELTA

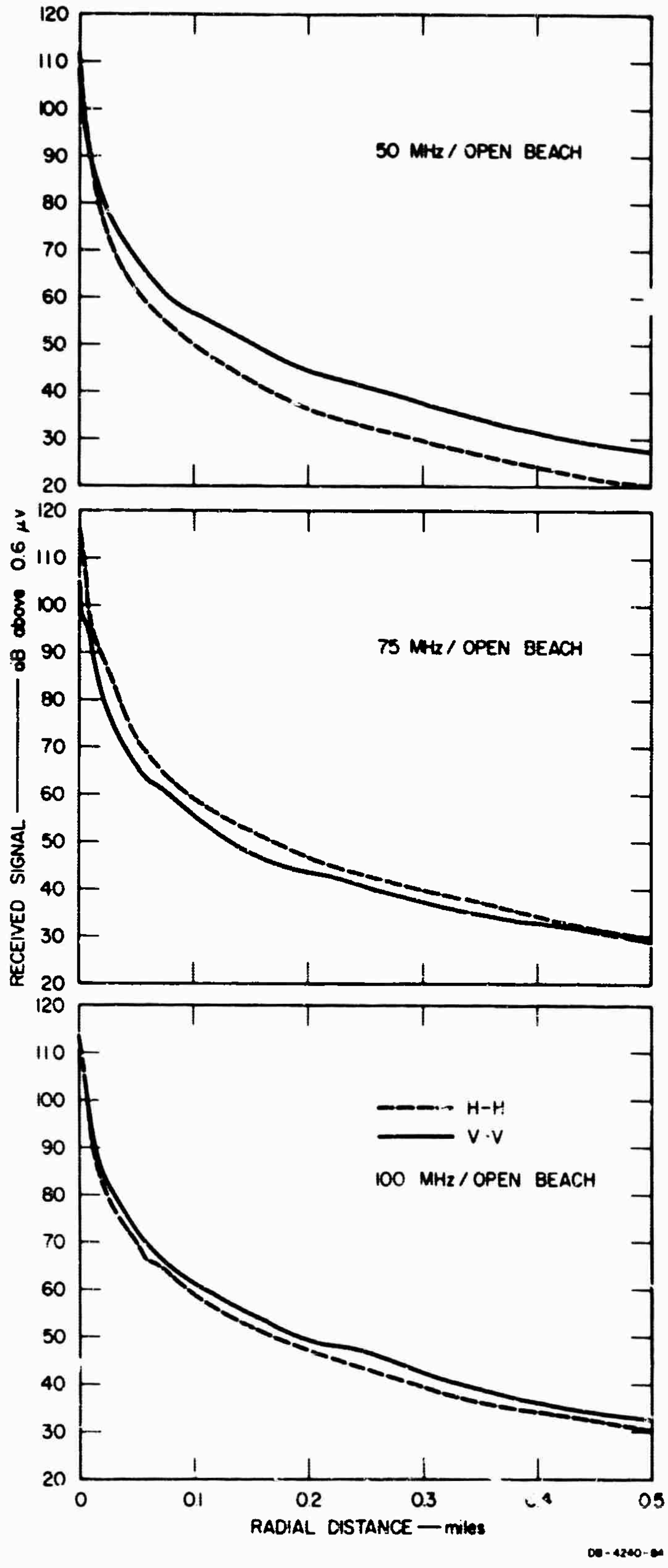



FIG. 21 POLARIZATION COMPARISONS FOR OPEN BEACH

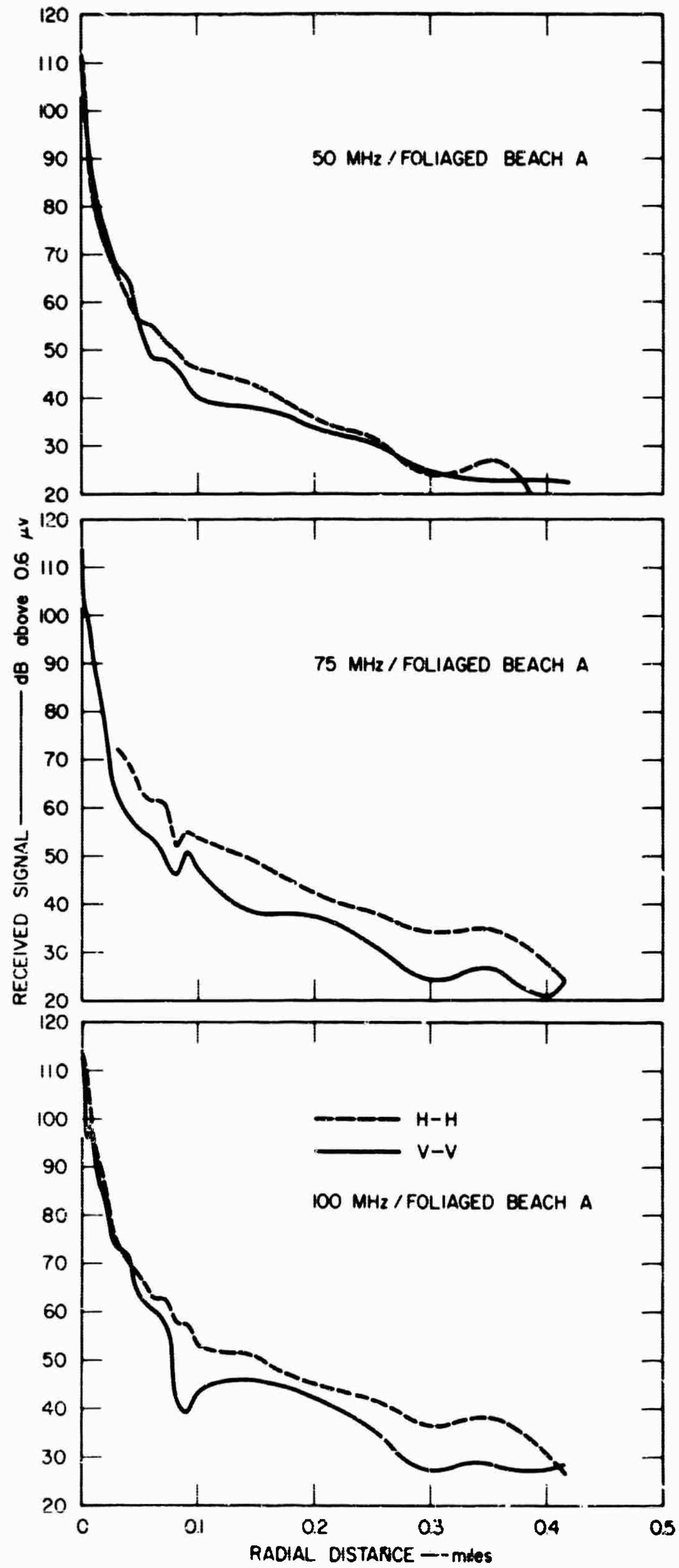



FIG. 22 POLARIZATION COMPARISONS FOR FOLIAGED BEACH A

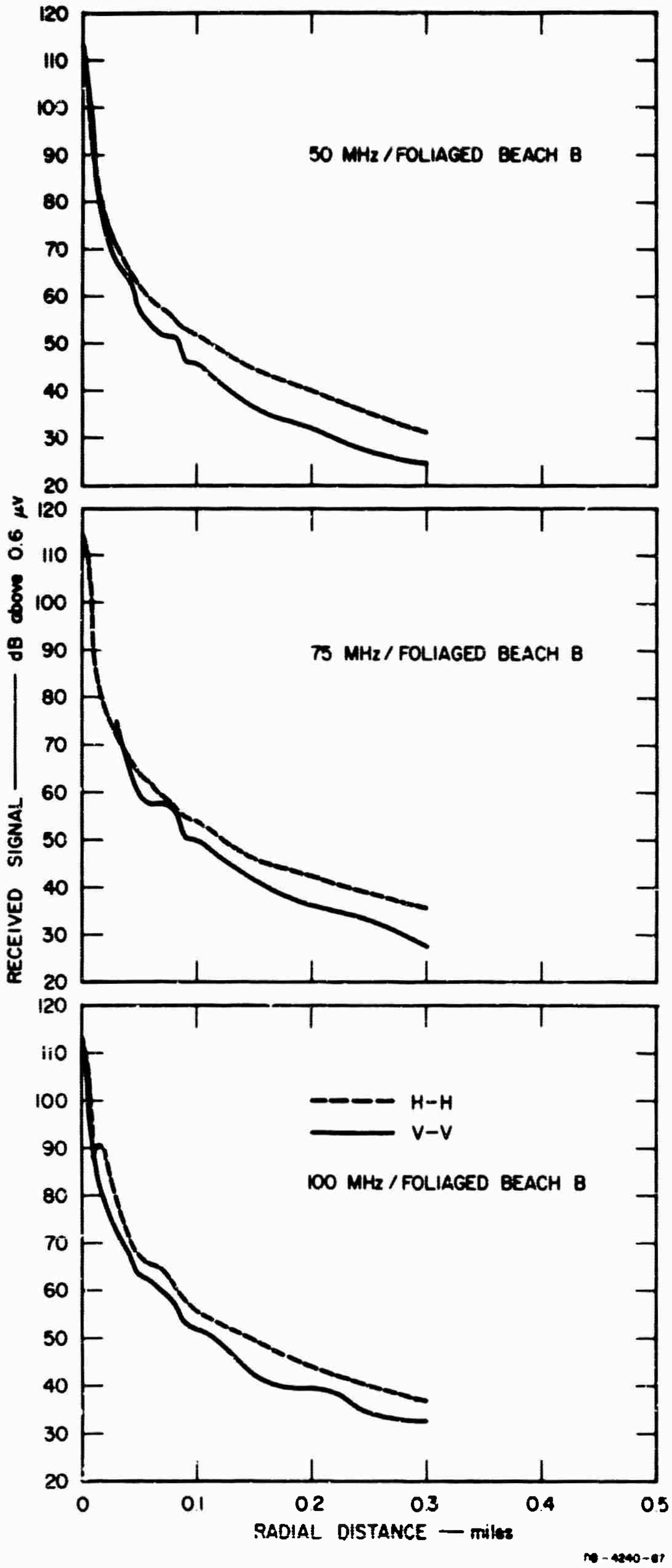



FIG. 23 POLARIZATION COMPARISONS FOR FOLIAGED BE⁄ ̄CH B

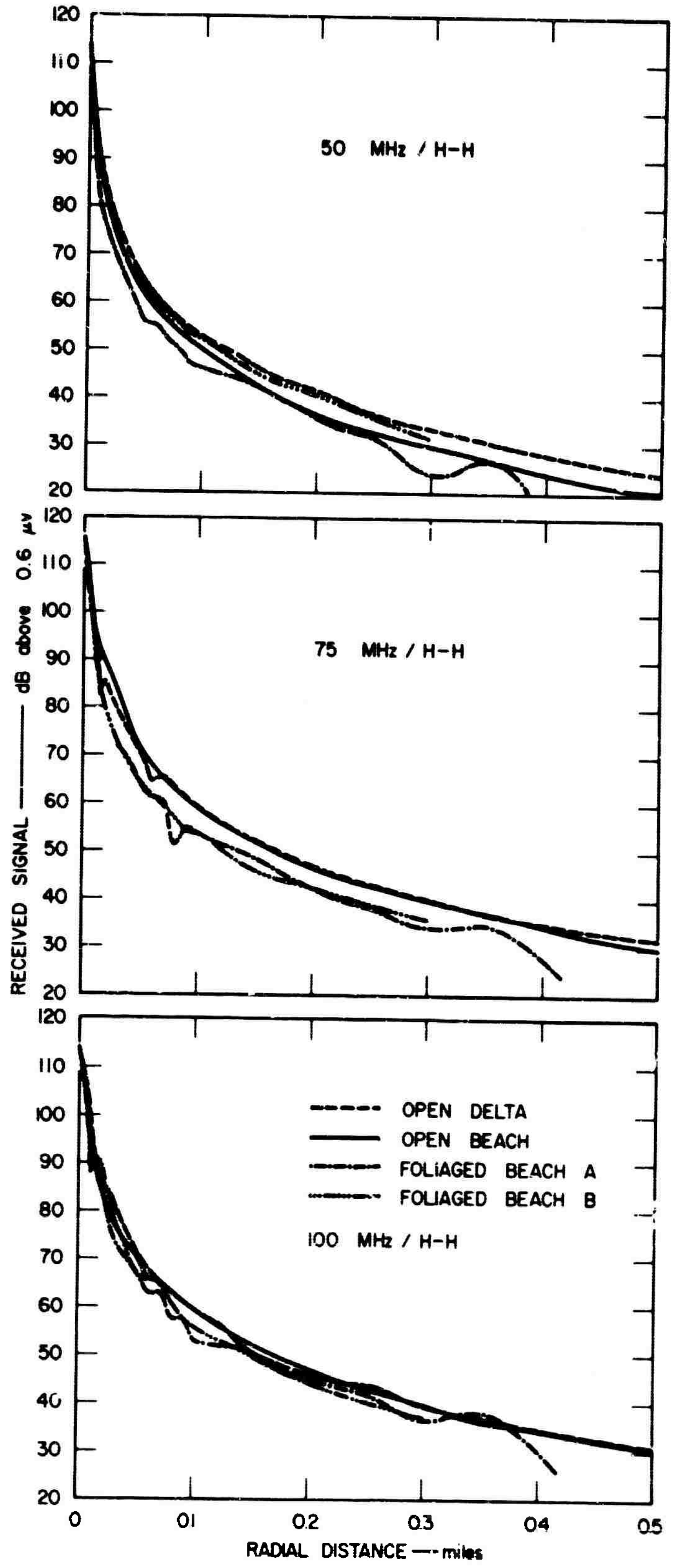



FIG. 24 TERRAIN COMPARISONS FOR HORIZONTAL POLARIZATION

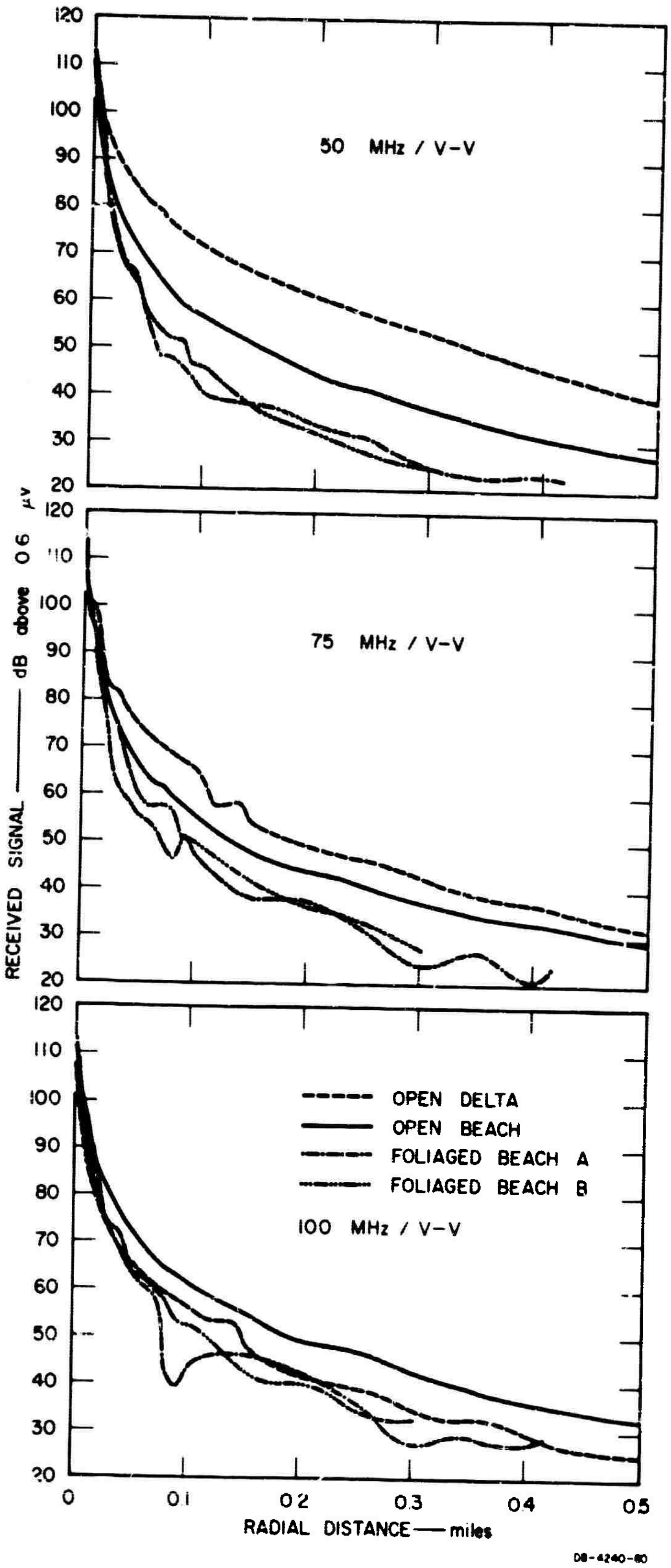



FIG. 25 TERRAIN COMPARISONS FOR VERTICAL POLARIZATION

# VII DISCUSSION

The results of this experiment provide an opportunity to examine the usefulness of the Xeledop system as a tool for studying VHF propagation problems. In addition, several interrelationships of frequency, polarization, and terrain were explored.

## A. Experimental System

The experiment was designed to obtain data that may be used to estimate the performance of typical manpack radio sets while at the same time overcoming the problems that make it difficult to conduct tests and evaluation with manpack sets themselves. The test setup desired was one that provides signals that can be transmitted over relatively long periods of time (several hours) at constant output levels and with little or no frequency drift. The receiving equipment must also be frequency-stable and be capable of producing an AGC signal having a large dynamic range. The basic data curves presented in Figs. 8 through 15, together with the experience of operating the Xeledop system, provides a means of assessing the use of the Xeledop system for manpack type measurements.

A test conducted to determine the stability of the signal output from the Xeledop transmitters showed that when the Xeledop transmitted CW (key down) simultaneously on three frequencies, the transmitter power output dropped less than 1 dB in 8 hours. Field experience with the Xeledop system showed that the system frequency drift is negligible during the period of a day. Frequent receiver calibration and tuning (before and after each round trip over the test trail) insures that the same frequency is being measured each time.

It has been previously stated that two round trips separated by as much as 24 hours in time were conducted during these tests. These time-separated runs were compared and a high degree of correlation was found to exist between them. This demonstrates the excellent stability and repeatability of measurement with the Xeledop system.

The standard deviations found in the open terrain results (Open Delta and Open Beach) also provide an excellent indication of the overall repeatability and stability of the Xeledop system. The deviations shown in the basic curves for the principal polarizations (H-H, V-V) are due principally to the effect of the relative position of the Xeledop and carrier with respect to the receiving antenna. A slight change in received signal occurred depending upon whether or not the man carrying the Xeledop was facing toward or away from the receiving antenna. This effect has be[illegible]sured and the difference in the received signal due to Xeledop ori[illegible]ion was 0.6 dB for an average of all readings and frequencies for H-H polarization. The difference in received signal, due to this cause, for V-V polarization was 2.3 dB. Deviations due to this cause are included in Sec. VI, Results, since no distinction was made between forward and reverse runs (i.e., walking away from or toward the receiving site) when the means and deviations of the received signal were computed.

An examination of Figs. 8 through 15 will show that the magnitude of the deviation of the received signal about the mean is approximately equal to deviation in the received signal due to the Xeledop's orientation to the receiving antenna. The average difference between the standard deviation and the orientation effect is less than 0.5 dB. This small difference can be attributed to the uncontrolled variations inherent in any experiment.

## B. Propagation Results

The comparison curves (Figs. 16 through 25) provide the basis for this discussion. While comparisons are made here only for the mean values of the received signal, it is recognized that the deviations will probably provide much information as well. However a suitable means of presenting that type of information has not yet been sufficiently developed for inclusion here.

An examination of both open-delta and open-beach data shows a decrease of signal with distance for nearly all frequencies and

polarizations investigated. This decrease follows closely a variation of inverse distance squared:

$$\text{Received signal is proportional to } \frac{1}{d^2}$$

where d is the distance.

The mean-value curves are within 1 to 3 dB of the $\frac{1}{d^2}$ curve.

The complex interrelationship of the effect of frequency, polarization and terrain upon the received signal strength makes it impossible to present a neatly organized discussion of the manpack Xeledop results.

Comparison curves have been prepared to help the reader interpret the results. However, by using data from the basic curves, the reader can make other comparisons that he finds interesting.

Some of the more interesting results shown in the comparison curves are as follows:

(1) The frequency comparison curves (Figs. 16 through 19) show that there is considerable consistency in the dependence of received signal upon frequency when the transmitting and receiving antennas are horizontal. For all terrains studied, the signal amplitudes at 75 and 100 MHz were approximately equal and were greater by 5 to 8 dB than signals at 50 MHz. The results of the measurements for vertical polarization are not as clear cut. In the open delta (good ground) the largest (vertical) signal was received at 50 MHz and the poorest at 100, with the difference in signal amplitudes ranging between 10 and 15 dB. For the open beach and foliaged trails A and B, however, the spread with frequency was much smaller and the signal amplitude at 100 MHz was somewhat higher than the signals at 50 and 75 MHz. It must be noted, however, that the radiation efficiency of the Xeledop is probably much greater near 100 MHz than at 50 MHz. The reason for this is that,

at 100 MHz, the Xeledop antenna is approximately $\lambda/2$, while at 50 MHz it is only about $\lambda/4$.

(2) The polarization comparison curves (Figs. 20 through 23) show that the dependence of received signal upon polarization is also complex. The results of the foliaged trail measurements show that the received signal for horizontal polarization was generally larger than for vertical for all frequencies. Over the open delta and beach, the signals for vertical polarization were substantially stronger at 50 MHz, but the difference between signals of the two polarizations was small at the higher frequencies.

(3) The terrain comparison curves (Figs. 24 and 25) show that for horizontal polarization there was little difference between the four paths measured. For vertical polarization, however, there were significant differences. The spread between signal amplitudes for the four paths was greatest at 50 MHz, with open delta giving by far the strongest received signal and the foliaged trail giving the weakest. The same trend was seen at 75 MHz although the magnitude of the spread between open delta and foliaged beach trails was considerably smaller. At 100 MHz the separation of received signal amplitude as a function of terrain was much less distinct and the largest signal was measured on the open beach.

## VIII CONCLUSIONS

The data and results presented in this report are limited to open terrain and dense undergrowth with a few scattered trees and are not intended to explore all terrain and foliage conditions. Interested readers should extrapolate results to other cases with caution.

Conclusions are as follows:

(1) The Xeledop system measuring technique provides a reliable method of studying propagation problems associated with manpack communications. The Xeledop has constant power and frequency outputs and the data obtained by this system has proven to be reliable and repeatable.

(2) Received signals vary approximately as inverse distance squared over open terrain. However, foliage causes significant transient departures from a $1/d^2$ variation.

(3) The frequency and polarization have significant effects on the received signals in the 50-to-100-MHz frequency range.

(4) Horizontally polarized signals are less affected by the type of ground or by foliage than are vertically polarized signals.

(5) Neither H-H nor V-V polarization was universally superior, though the results indicate that operation with H-H polarization may be best in all but flooded areas.

(6) Differences in the effect of similar types of foliage on received signals cannot be distinguished

by the techniques described here. More work is required to extend these techniques to distinguish between the effects of similar types of foliage on received signals.

## IX FUTURE WORK

The Xeledop technique has proved to be a useful tool for exploring foliage propagation problems. Several improvements in the system and in data processing are planned or in progress. Several experiments are also being considered.

The Xeledop is designed to transmit simultaneously on three frequencies. A simultaneous three-frequency recording set-up has been tested and will be used in future measurements. The development of a suitable analysis and presentation of data where fading is predominant is underway. Examples of data having large fading characteristics are cases of cross-polarization and data taken in forests having large trees. This effort may also provide the statistical capability of distinguishing propagation differences, if any, in similar forests.

It is planned to make measurements in several types of forest in order to compare propagation characteristics. These measurements will be coordinated with open wire transmission line[5] and Environmental Research foliage-classification studies. A simultaneous approach of this nature will provide a body of data useful in modeling forest effects on radio propagation.

An important study comparing the Xeledop system results with tactical manpack radio systems has been started. The objective of this is to develop a method of relating VHF manpack radio systems to the Xeledop technique. Once the relationship has been established, it would be possible to predict the effective range of selected manpack radios in foliage by examining results obtained by Xeledop measurements.

Other manpack-oriented investigations that can be conducted with the Xeledop technique include evaluation and comparison of various types of antennas, antenna height gain studies (elevation of both transmitting and receiving antennas), and the scattering effect of trees, singly and in groups.

Appendix A

MANPACK RECEIVING ANTENNAS

Appendix A

# MANPACK RECEIVING ANTENNAS

## 1. CONSTRUCTION

The receiving antennas are balanced, half-wave dipoles that were designed to be portable, self supporting, and adjustable. The antenna elements are telescoping automobile antennas and can be adjusted to operating length between frequencies of 50 and 100 MHz.

A North Hills model 1100 BB 1:1 balun transformer is mounted near the antenna feed point. A 2-foot arm of phenolic material supports the antenna elements. This arm also serves as a support to keep the transmission line perpendicular to the antenna elements for the first 2 feet beyond the antenna connection. The antenna support arm is fastened to a wooden mast section by a clamp that allows the antenna to be rotated to any desired polarization. The antenna mast is supported by a wooden tripod that provides a convenient means of leveling the antenna and adjusting the antenna's height over irregular terrain. Three such antennas were constructed.

## 2. ANTENNA ADJUSTMENTS AND IMPEDANCE MEASUREMENTS

The operating length of each antenna was found by adjusting the antenna elements until the antenna became resonant when it was located over open delta terrain with horizontal polarization and a feedpoint height of 10 feet. The antenna half-length (measured from the feedpoint to one end) for each frequency was found to be:

| | |
|---|---|
| 50 MHz | 56.25 inches |
| 75 MHz | [illegible] inches |
| 100 MHz | 30.25 inches |

The length thus found, as well as the feedpoint height of 10 feet, was used for all other test locations and polarizations. Measurements

were made at each location, for both vertical and horizontal polarizations, to determine any change in the impedance of each antenna. These measurements also serve as a check on the antenna prior to performing the Xeledop tests.

The antenna impedance measurements were made with a Boonton Type 250-A RX meter. The antennas were connected to the bridge by a coaxial cable whose length was an even number of half-wavelengths at each frequency measured. The impedance values found are given in Table A-1.

Table A-1 shows that the type of terrain has more effect on the antenna's impedance at the lower frequencies. This is probably due to the generally larger ground "heating losses" from electrical proximity at the lower frequencies. The effect is also larger for vertical polarization at 50 MHz. This may be due to the fact that the 50-MHz antenna element is physically closer to the ground than the 100-MHz element. Table A-1 also indicates that the impedances of the antennas were rather insensitive to the surrounding foliage, since no large change was measured between impedances when the antennas were over open sand and impedances when the antennas were nearer the foliage.

Table A-1

MEASURED IMPEDANCES

(Ohms)

| HORIZONTAL POLARIZATION | | | | |
|---|---|---|---|---|
| Frequency (MHz) | Open Delta | Open Beach | Foliaged Beach A | Foliaged Beach B |
| 50 | 37.3∠0° | 41.8∠0° | 41.7∠-1.6° | 41.5∠1.4° |
| 75 | 59.2∠0° | 58.1∠1.5° | 58.1∠1.5° | 63.1∠4.7° |
| 100 | 55.9∠0° | 57.4∠1.0° | 57.5∠2.5° | 55.3∠0.6° |
| VERTICAL POLARIZATION | | | | |
| 50 | 39.0∠6.2° | 43.8∠7.2° | 43.8∠5.4° | 42.0∠7.9° |
| 75 | 61.1∠1.4° | 60.0∠1.3° | 58.0∠2.4° | 62.5∠5.2° |
| 100 | 54.8∠-1.2° | 57.1∠0.8° | 57.8∠1.6° | 55.6∠0° |

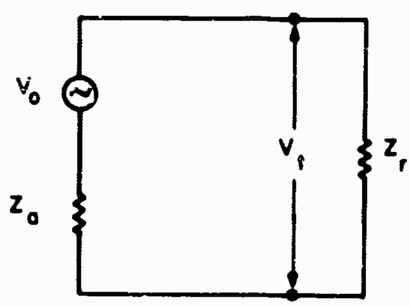
3. MEASUREMENT ERROR DUE TO CHANGES IN ANTENNA IMPEDANCE

Table A-1 shows that the measured impedances of the manpack antennas change at the different test locations. These impedance changes will introduce some error into the measurement of the received signal strength, and consideration should be given to the amount of error involved.

Section VI of this report presents the variation of the received signal with radial distance. The received signal is the voltage measured across the terminals of the receiver. The value of this voltage is determined by comparing the received voltage to a known voltage produced by a calibration signal generator. Thus the receiver and strip-chart recorder combination is nothing more than a frequency-selective RF voltmeter capable of providing a permanent record of the received voltage.[6]

An error in this measurement can occur because of the substitution of the signal generator for the antenna for calibration purposes. If the antenna has the same impedance as the signal generator, then the receiver (RF voltmeter) will see the same impedance and no error will result. However, when the antenna impedance differs from that of the generator an error will occur. The extent of this error can be determined from the following.

The equivalent circuit of the antenna connected to the RF voltmeter (receiver) is drawn below;




where

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$V_o$ = Open-circuit antenna voltage, volts

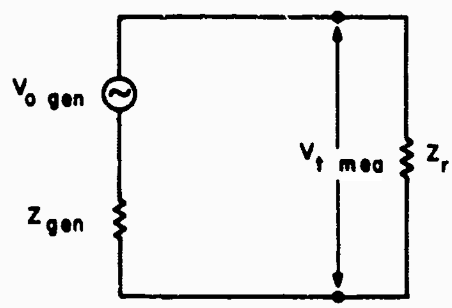
$Z_a$ = Antenna impedance, ohms

$Z_r$ = Receiver input impedance, ohms.

It can be seen from the circuit that the voltage across the receiver terminals, $V_t$, is

$$V_t = \frac{V_o(Z_r)}{Z_a + Z_r} \quad . \tag{A-1}$$

The value of $V_t$ is found by replacing the antenna by the signal generator. The following diagram represents this measurement:




D-4240-1226

where

$V_{o\ gen}$ = Open-circuit generator voltage, volts

$Z_{gen}$ = Generator impedance, nominally 50 Ω

$V_{t\ mea}$ = Measured terminal voltage, volts.

Thus, the measured voltage is given by

$$V_{t\ mea} = \frac{V_{o\ gen}(Z_r)}{Z_{gen} + Z_r} \quad . \tag{A-2}$$

The measurement of the received voltage is accomplished by adjusting the signal generator voltage ($V_{o\ gen}$) until $V_{t\ mea} = V_t$. When this is done the following becomes true:

$$\frac{V_{o\ gen} Z_r}{Z_{gen} + Z_r} = \frac{V_o Z_r}{Z_a + Z_r}$$

$$V_o = \frac{Z_a + Z_r}{Z_{gen} + Z_r} V_{o\ gen} \quad . \tag{A-3}$$

Equation (A-3) shows how an impedance mismatch between the generator and antenna affects the accuracy of measuring $V_o$.

As an example, consider the case where $Z_{gen} = 50\ \Omega$ and $Z_a = 63\ \Omega$. This represents one of the largest impedance magnitude mismatches, as given by Table A-1.

Substituting the impedance values in Eq. (A-3) gives

$$V_o = \frac{63 + 50}{50 + 50} V_{o\ gen}$$

$$= \frac{113}{100} V_{o\ gen} \quad .$$

Taking logs gives:

$$20 \log_{10} V_o = 20 \log_{10} \frac{113}{100} + 20 \log V_{o\ gen}$$

$$= 20\ (.052) + 20 \log V_o \text{ gen}$$

$$= 1.04 + 20 \log V_{o\ gen} \quad .$$

Thus, the error caused by a 13 Ω mismatch causes a relative error of about 1 dB in the measurement of $V_o$.

Appendix B

ENVIRONMENTAL REPORT ON FOLIAGED BEACH TERRAIN

By

Staff Members of MRDC Environmental Sciences Division

## Appendix B

## ENVIRONMENTAL REPORT ON FOLIAGED BEACH TERRAIN

### 1. INTRODUCTION

A description of the terrain in the test area is an important requirement to the successful study of manpack communications. These environmental studies aid in comparing radio set or propagation tests made at different sites by different researchers. They also provide input data required for making models of the environment suitable for theoretical studies.

The plots discussed in this report are four of several hundred made throughout Thailand by the Environmental Sciences Division of MRDC.[7] These plot studies were made in support of the manpack Xeledop program. However, the results are also included in the general environmental study of Thailand being conducted by MRDC.

### 2. DATA COLLECTION AND ANALYSIS

The foliage sites described in this report were inventoried by a forestry team from the Royal Forest Department under ARPA contract. These data were gathered by techniques established by the Environmental Sciences Division of MRDC.

Three types of data were obtained during the inventory. These were foliage, visibility, and soil data. The following is a brief description of the collection methods used for the inventory reported here.*

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*A more comprehensive description of inventory methods is given in Ref. 7. It should be noted that generally the inventory is made on trees above 5 cm in diameter. This was not possible at the sites reported here, since few large trees exist in the area. However, the inventory procedure is the same regardless of the minimum tree size specified for inventory.

a. Foliage Data

The foliage inventory was conducted in four plots, two for each test trail. These sample plots were chosen to check the foliage characteristics around the receiving antennas and along the test trails at a radial distance of 0.1 mile.

Measurements in each plot consist of identification of flora, a record of the foliage height, and the number of plants in a 10-by-10-meter sample within the plot. A plan view sketch of each plot gives the location and coverage of the flora within the plot.

b. Visibility

The dot count system is the method used in measuring forward visibility. Many tests have been devised that are designed to measure the screening effect of vegetation. The end product of these tests is a set of numbers related to the visibility that will be analyzed to yield a visibility index for the particular plant assemblage represented by the sample.

The dot count system is thought to provide a more valid index of forward visibility than any procedure previously employed in Thailand. It is at least standard and objective, and reduces to a minimum the effect of extraneous factors presumed also to influence visibility, such as the color of the target and various physiological or psychological reactions of individual observers. The dot method consists of counting dots painted on a white disc.

The disc is moved along radials each seperated by 45° in azimuth, and a count is made at 5-meter intervals until no dots can be counted. Counting is accomplished using binoculars, with the observer located in the center of the test plot. A plane table was set up in each plot, with the binoculars mounted on it. The target used had three white discs, each one foot in diameter and having 25 red dots 1/8 inch in diameter thereon. These are the discs referred to later, on the figures showing visibility data. The dots counted visually were recorded for each position of the target, and from these data, horizontal

visibility curves, expressed as the percentage seen of the total number of dots on the target, or on each disc, may be graphed as a function of target-to-viewer separation. The percentages so obtained are called % Visibility in this appendix.

c. Soil Sample

Soil samples are collected for each forest profile to a depth of 72 inches or to bedrock. A bucket auger is used to drill the 72-inch-deep vertical soil profiles. The gradation curve and determination of specific gravity, natural soil moisture, plastic limit, and plastic indices were done at the SEATO laboratory. Other soil tests were carried out in the field according to two soil-classification systems. One of these is known as the United States Department of Agriculture (USDA) system and the other is called the United States Classification System (USCS).

The soil test consists of measurements of pH, soil color, cone index, soil texture, water table, and permeability. Water table height is noted if it is within 72 inches of the surface. Permeability is noted as being "rapid," "moderate," or "poor."

3. RESULTS

a. Foliage

1) Foliaged Beach A

Slope: 0%

Elevation: 5 meters

Exposure: N34°W

This test trail is perpendicular to, and begins about 100 meters from, the seashore. The vegetation is scrub growth and is classified as evergreen beach forest although it was composed mainly of shrubs, bushes, climbers, and thorny succulent herbs. Few trees taller than 10 meters can be found in this area.

The undergrowth in the test plots along this trail is a dense, tangled mass that provides very poor penetration and visibility.

This undergrowth has an average height of 2.5 to 6 meters. The type of undergrowth indicates that the original forest has been disturbed. Nearly all the useful trees are gone. A stem analysis of coppice* growth indicated that the forest was heavily disturbed more than 30 years ago. The few remaining trees in the area belong to Dipterocarpus Costatus, Irvingia Malayana, and Ficus species. The number of woody plants, including climbers of larger than 1 cm diameter in a 10-by-10-meter sample, is 355.

Figure B-1 (plots 306 and 307)† is a plan-view sketch of the sample plots. One plot (306) is of foliage around the antenna site while the other (307) was located at a radial distance of 0.1 mile.

2) Foliaged Beach B

The physiographical features of this test site are similar to the Foliaged Beach A test area. The forest stand is less dense at this site and there are more cactus plants. This trail is about 2.5 meters wide and is located parallel to, and about 150 meters from, the seashore.

Throughout the test site many stumps with coppices are present, indicating that most of the tree species have been cut. The present ground cover is secondary. The vegetation is composed of prickly or thorny plants such as Opuntia Sp., Atalantia Monoplylla, Azima Sormentosa, Harrisonia Perfocata, Streblus Sp., and Randia Tomentosa. An examination of the plan views given in Fig. B-2 (plots 304 and 305) shows that the cactus plant Opientia Sp. covers almost the entire area. The reason for a greater predominance of cactus at this site, as compared to Foliaged Beach A, is the density of the foliage. Cactus is a strong-light-demanding species and densely foliaged areas such as found along Trail A block the light.

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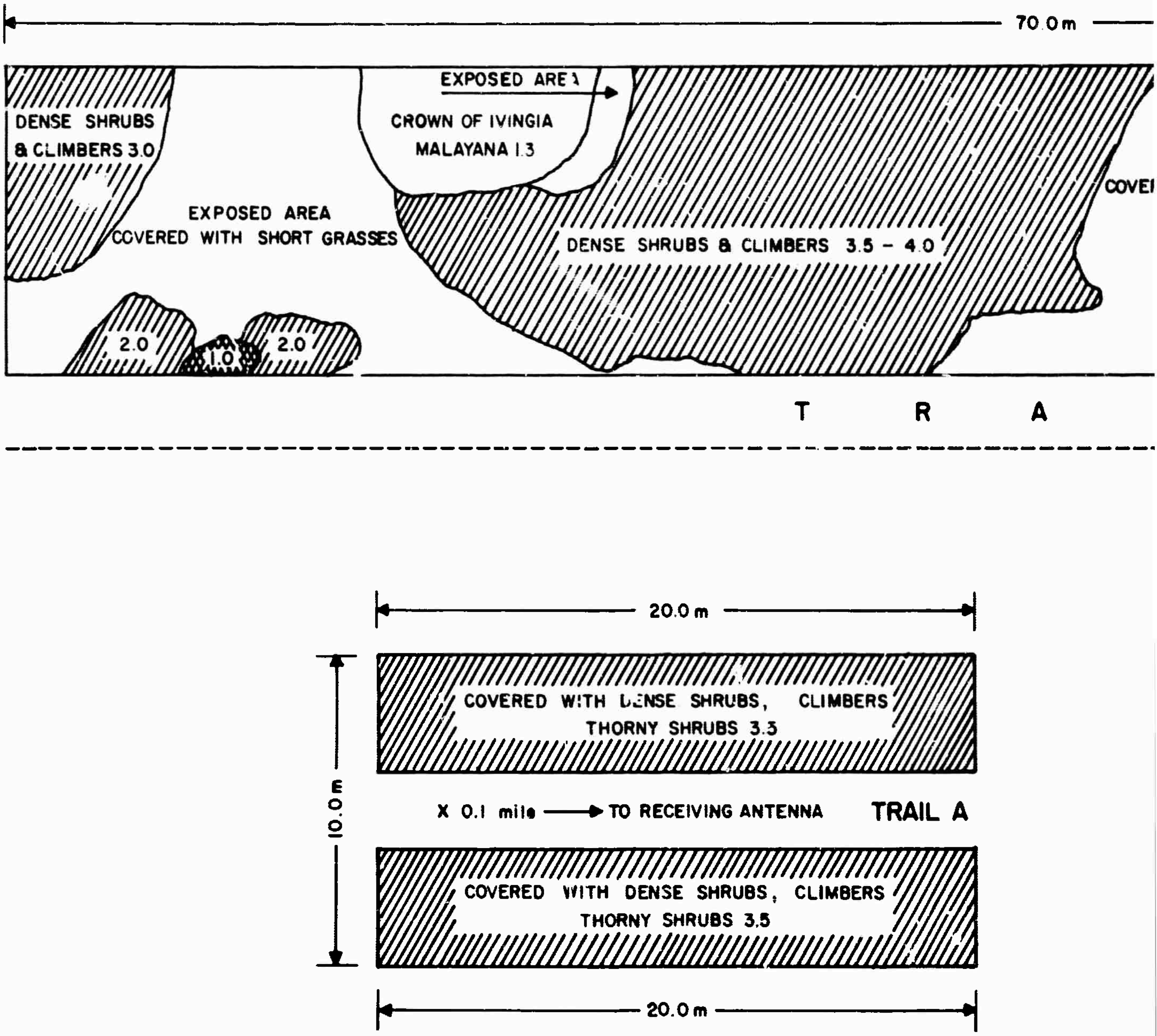
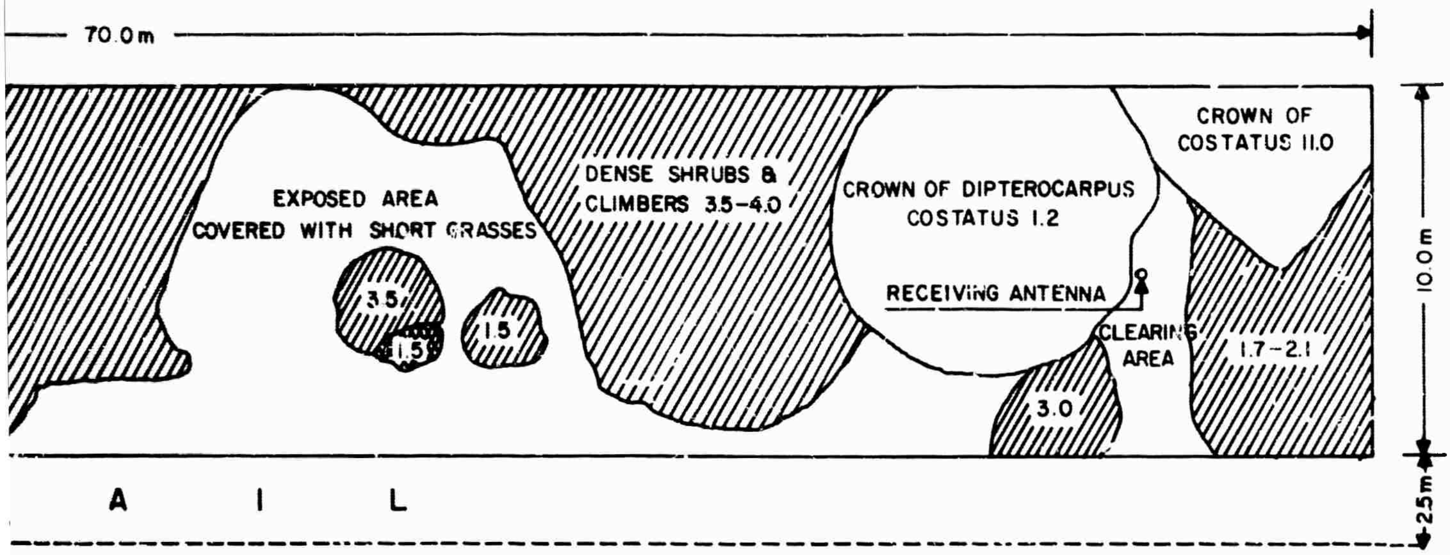
*A thicket or a grove of small trees originating primarily from sprouts.

†Refers to MRDC inventory number.

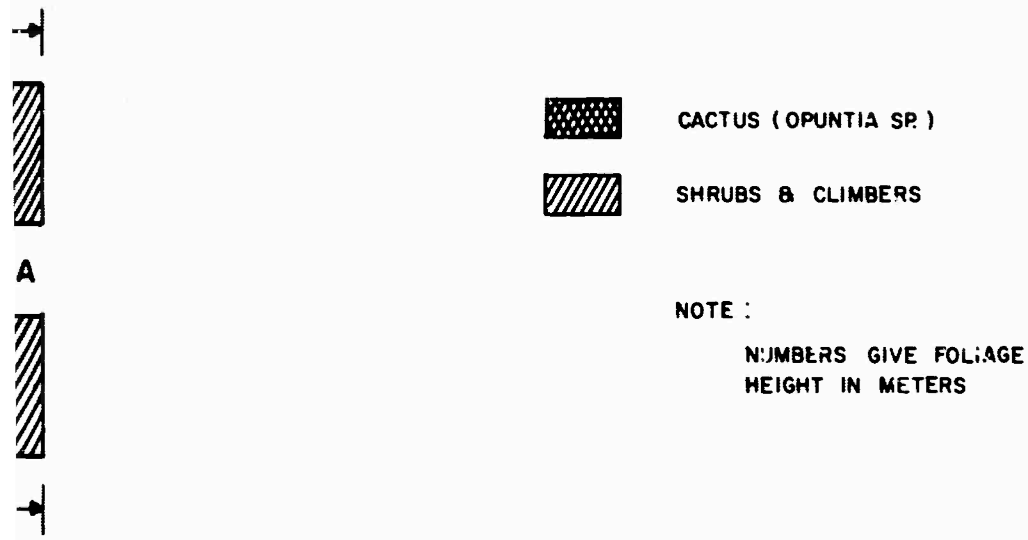



PLOT 307 ( AT 0.1 mile )

FIG. B-1 PLAN VIEW OF SAMPLE PLOTS




PLOT 306 (ANTENNA SITE)

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OF SAMPLE PLOTS FOR FOLIAGED BEACH A

Fig. B-1

B

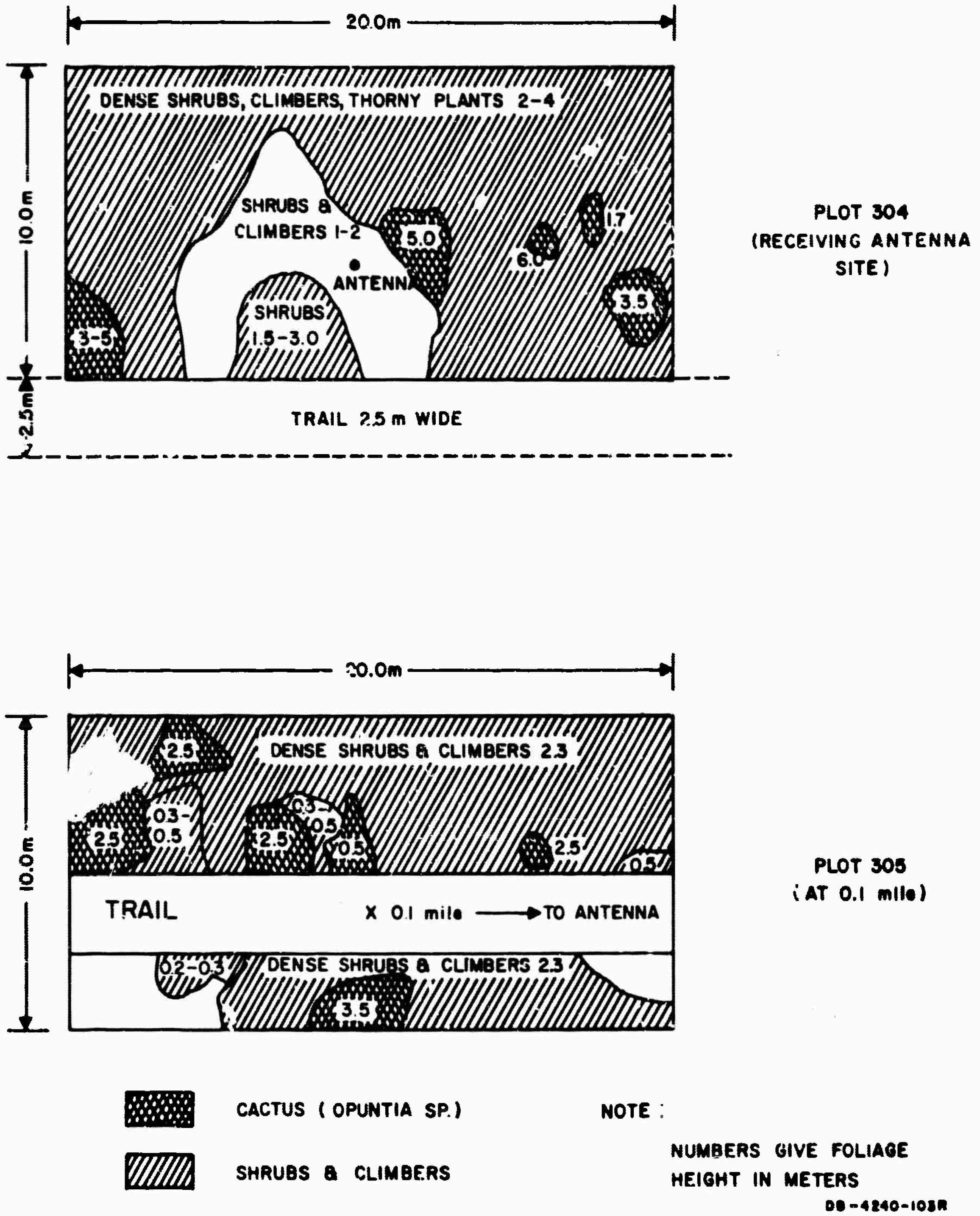


FIG. B-2 PLAN VIEW OF SAMPLE PLOTS FOR FOLIAGED BEACH B

The number of wood plants and cacti of 1 cm in diamter or larger in a 10-by-10-meter sample plot is 216. Trees higher than 10 meters are not found in the test plots.

The test site is covered by vegetation of different heights, with open gaps often found along the test line. In certain areas the vegetation forms a stand 4.5m high and in other localities it consists of dwarf shrubs 40 cm high. Owing to the tangled mass of climbers, only a few trees are able to display their characteristic canopies; penetration without clearing the path is impossible in this area. The visibility is very limited.

The following are the plant species that grow along both test trails and in the test area (for both Trails A and B)

Trees: Dipterocarpus Intricatus, Ficus Lacor.

Shrubs: Randia Tomentosa, Hydnocarpus Ilicifolius, Anacardium Orientale, Otophora Fruticosa, Atalantia Monophylla, Azima Sarmentosa, Pongamia Glabra, Harrisonia Perforata, Streblus Asper, Calophyllum Inophyllum, Flacourtia Sp., Opilia Amentacea, Rhinorea Sp., Micromelum Hirsutum, Lasianthus Sp., Buxus Sp., Ochana Harmandii, Memecylon Sp., Diospyros Sp., Santalaceae, Glycosmis Sp., Casearia Grewiifolia, Derris Sp.

Herbs: Kalanchoe Pinnata, Euphorbia Sp., Aglaonema Ovatum, Polycarpaea Corymbosa, Eupatorium Odoratum, Euphorbia Sp.

Climbers: Acacia Comosa, Capparis Sp., Jasminum Sp., Canavalia Cf. Miritima, Aganosma Sp., Tiliacora Sp.

Parasites: Dendrophthoe Pentandra.

b. Visibility

1) Foliaged Beach A

Figure B-3 gives curves of percent horizontal visibility vs. distance for the plots measured on this trail (Plots 306 and 307). A comparison of the average visibilities of Fig. B-3 shows that the visibility is much reduced in the foliage present at 0.1 mile as compared to that at the receiving antenna site. For example, at 10 meters, visibility is 44% at the antenna site and 22.5% at the site at 0.1 mile.

2) Foliaged Beach B

Figure B-4 presents horizontal-visibility-vs.-distance curves for Trail B. The curves show that visibility is nearly the same for both test plots (304 and 305) of this trail.

c. Soil Samples

1) Foliaged Beach A

a) Antenna-Site (Plot 306) Soil Characteristics

Depth--0 to 2 Inches

Surface was covered with dry leaves 1/4 inch deep. Humus, very dark gray (5 YR 2/1) in color, was present in this layer and was joined together giving a lumpy appearance. Sub-surface was classified as SW by USCS and as well graded sand by USDA, consisting of 40% coarse sand, 40% medium sand, 18% fine sand, and 2% silt. Maximum grain size is 2.5 mm. The grains are different colors, consisting of dark gray brown (10 YR 4/2), light reddish brown (5 YR 6/6), and pinkish white (5 YR 8/2). Soil is single-grained, non-coherent, dry and loose. When wet its consistency is non-plastic and non-sticky. Permeability is good.

Depth--30 Inches and Below

A sample below 30 inches could not be obtained with the auger because the soil was too loose. The following table gives the pH values and Cone Index for Plot 306.

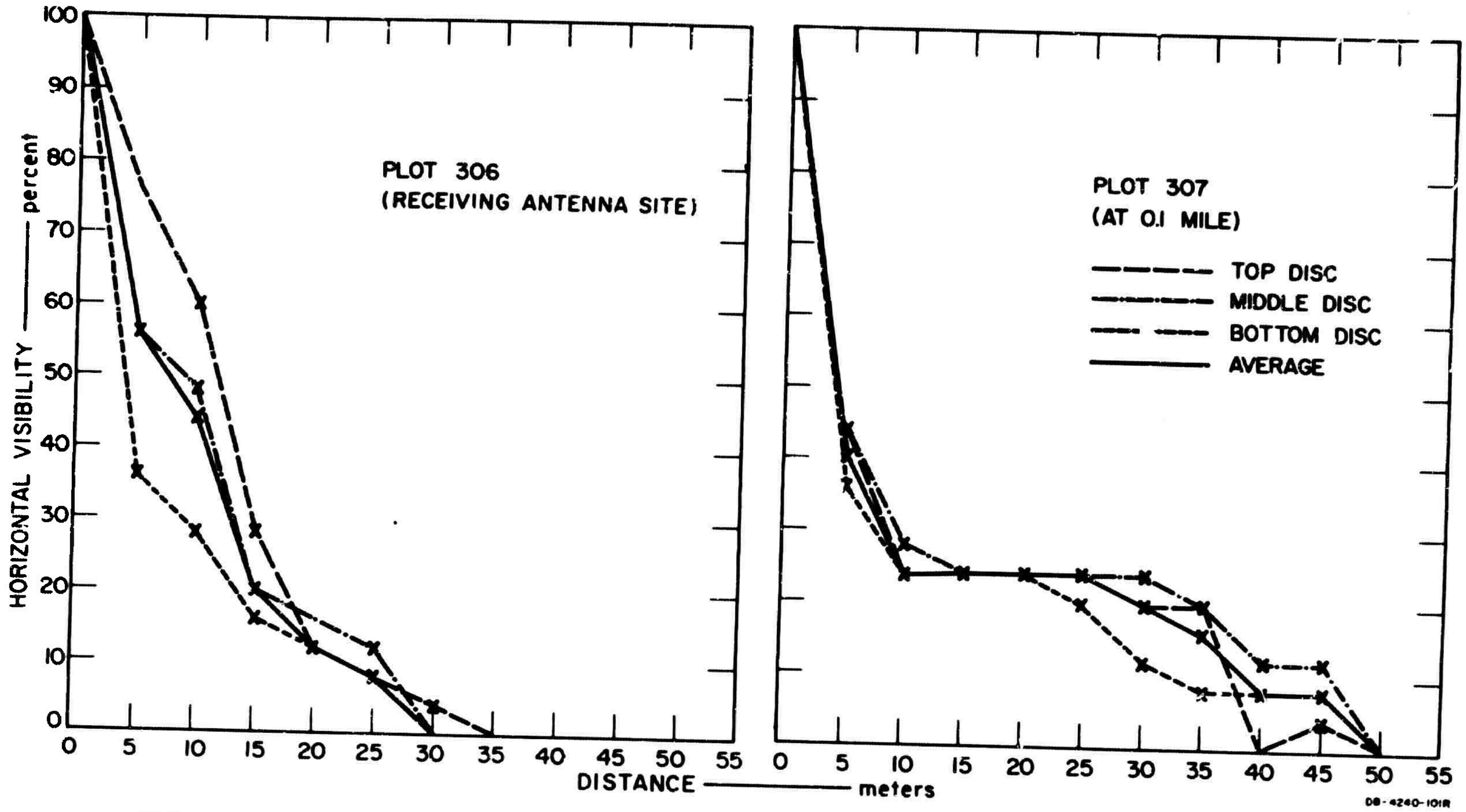


FIG. B-3 HORIZONTAL VISIBILITY vs. DISTANCE OF SAMPLE PLOTS FOR FOLIAGED BEACH A

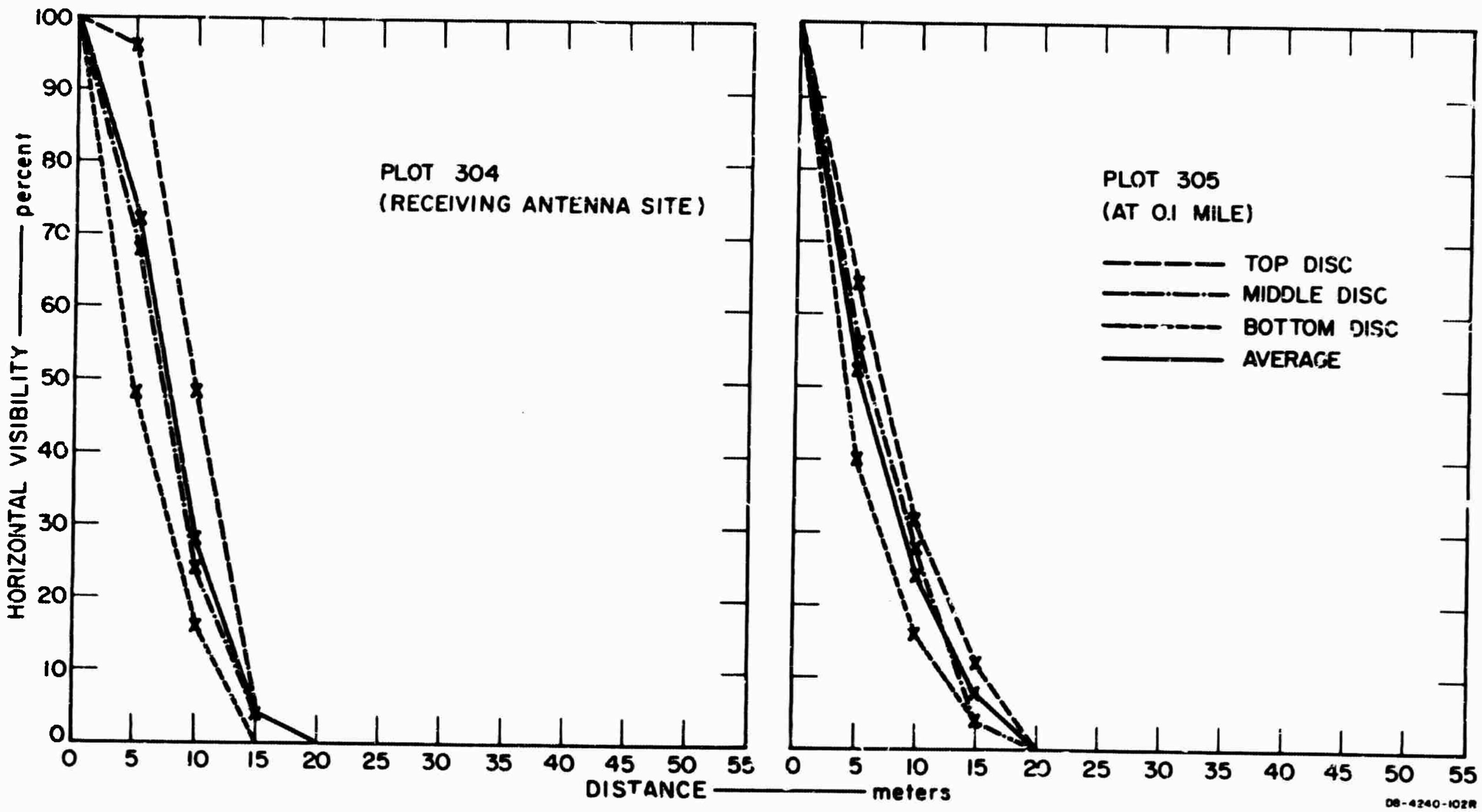


FIG. B-4 HORIZONTAL VISIBILITY vs. DISTANCE OF SAMPLE PLOTS FOR FOLIAGED BEACH B

| Depth (inches) | pH Value | Depth (inches) | Cone Index |
|---|---|---|---|
| 0 | 6.6-7.5 | 0 | 10 |
| 3 | 6.5 | 3 | 130 |
| 6 | 6.2 | 6 | 190 |
| 12 | 6.2 | 9 | 230 |
| 24 | 6.2 | 12 | 240 |
| 30 | 6.2 | 15 | 250+ |
| | | 18 | 250+ |

b) <u>Soil Characteristics at 0.1 Mile (Plot 307)</u>

Soils on this plot are identical to those in plot 306, and again below 30 inches a sample could not be obtained. The following table gives pH values and Cone Index for Plot 307.

| Depth (inches) | pH Value | Depth (inches) | Cone Index |
|---|---|---|---|
| 0 | 6.0-6.6 | 0 | 25 |
| 3 | 5.5 | 3 | 85 |
| 6 | [illegible].7 | 6 | 160 |
| 12 | 6.0 | 9 | 220 |
| 26 | 6.0 | 12 | 250 |
| 30 | 6.0 | 15 | 286+ |
| | | 18 | 300+ |

2) <u>Foliaged Beach B</u>

a) <u>Antenna-Site (Plot 304) Soil Characteristics Depth--0 to 6 Inches</u>

Surface was covered with many roots and some liter and humus. Subsurface was classified as SW by Unified Soil Classification System (USCS) and as well graded sand by United States Department of Agriculture (USDA). Consisted of 6% gravel, 70% coarse sand, 18% medium sand, 4% fine sand, and 2% silt. Maximum grain size is 2.5 mm,

of angular and subangular shape. The grains are of different colors consisting of pinkish gray and shown on comparative color charts (5 YR 6/2) light reddish brown (5 YR 6/4), light gray (10 YR 7/2), very pale brown (10 YR 7 ), red (2.5 YR 5/6), and reddish brown (2.5 YR 5/4).

Depth--6 to 45 Inches

Soil is single-grained, dry and loose. Consistency when wet is non-plastic and non-sticky. Permeability is good. Classified as SW by USCS and as well graded sand by USDA. Consisting of 5% gravel, 64% coarse sand, 26% medium sand, 4% fine sand and 1% silt. The grains are of different colors consisting of light reddish brown (5 YR 6/4), yellowish red (5 YR 5/6), light brown (7.5 YR 6/4), and pinkish white (7.5 YR 8/2). These colors were measured in a moist soil condition. The soil was dry to 13 inches in depth and moist below. Soil is single-grained, loose and friable in moist condition. Consistency when wet is non-plastic and non-sticky. Permeability is good.

Depth--45 Inches and Below

A sample could not be obtained with the auger due to the loose consistency of the soil. The following table gives the pH values and Cone Index for Plot 304.

| Depth (inches) | pH Value | Depth (inches) | Cone Index |
|---|---|---|---|
| 0 | 5.5-5.8 | 0 | 15 |
| 6 | 5.5-5.7 | 3 | 95 |
| 12 | 5.7 | 6 | 180 |
| 24 | 5.7 | 9 | 265+ |
| 38 | 5.8 | 12 | 290+ |
| 45 | 6.0 | 15 | 300+ |
| | | 18 | 300+ |

b) Soil Characteristics at 0.1 Mile (Plot 305)

Soils on this plot are identical to those in Plot 304 with one exception. At 30 inches in depth it was not possible to obtain a sample with the auger due to the loose consistency of the soil. The following table gives the pH values and Cone Index for Plot 305.

| Depth (inches) | pH Value | Depth (inches) | Cone Index |
|---|---|---|---|
| 0 | 5.6-5.8 | 0 | 10.5 |
| 6 | 5.6 | 3 | 65 |
| 12 | 5.6 | 6 | 141 |
| 24 | 5.7 | 9 | 234 |
| 30 | 5.7 | 12 | 286+ |
| | | 15 | 300+ |
| | | 18 | 300+ |

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UNCLASSIFIED
Security Classification

# DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Stanford Research Institute<br>333 Ravenswood Avenue<br>Menlo Park, California | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b. GROUP<br>N/A |

3. REPORT TITLE

INITIAL VHF PROPAGATION RESULTS USING XELEDOP TECHNIQUES AND LOW ANTENNA HEIGHTS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Special Technical Report 26

5. AUTHOR(S) (First name, middle initial, last name)

Nicholas K. Shrauger, Kenneth L. Taylor

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| December 1966 | 98 | 7 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO.<br>Contract DA-36-039 AMC-00040(E)<br>b. PROJECT NO.<br>Order No. 5384-PM-63-91<br>c.<br>ARPA Order No. 371<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>Special Technical Report 26<br>SRI Project 4240<br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) |

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited.

| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY |
|---|---|
| | Advanced Research Projects Agency<br>Washington, D.C. |

13. ABSTRACT

An adaptation of the Xeledop technique for study of propagation problems associated with VHF manpack radios is described and the results of initial VHF propagation tests for several frequencies, polarizations, and terrains for low antenna heights are presented.

Initial results show that the choice of frequency and antenna polarization has a significant effect on propagation in a situation similar to a possible employment of manpack radio sets. Vertical polarization was found to be superior for transmission of signals over open terrain; horizontal polarization was superior for the foliage-covered terrain of the tests. The effect of frequency was also examined and it was found that the type of terrain generally has less effect on the received signals as the transmission frequency is increased from 50 to 100 MHz.

Future propagation studies and measurements using the Xeledop technique are suggested.

| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| VHF Propagation | | | | | | |
| Southeast Asia | | | | | | |
| Thailand | | | | | | |
| Terrain Effects | | | | | | |
| Foliage Effects | | | | | | |
| Foliage Mensuration | | | | | | |
| Manpack Radios | | | | | | |
| Xeledop Technique | | | | | | |
| Signal Strength | | | | | | |
| SEACORE | | | | | | |